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EXPLOITATION OF THE ROȘIA MONTANĂ GOLD DEPOSIT, TECHNICALLY POSSIBLE AND ECONOMICALLY EFFICIENT

Victor ARAD[1], Alina GHENESCU PLEȘA[2], Dumitru Adrian PRAȚIA[3], Georgiana PRAȚIA[3], Adrian BUDA[3], Sergiu Bogdan POP[3]

Abstract: *In Romania, numerous geotechnical and geomechanical studies have been carried out for the rocks collected from the mining perimeters of the gold-bearing quadrangle of the Apuseni Mountains. The paper presents a study for the exploitation of gold from the Roșia Montană mining perimeter by a new project. It also analyzed the possibility of using the rocks from the excavations for the construction of terrestrial communication roads and the priming dike for the settling pond. The rocks were also checked for their suitability for use in construction in the manageability classes according to the standards.*

Key words: *Cyanidation, exploitable contents, environmental impact, admissibility conditions*

1. INTRODUCTION

Mineral resources have returned to the center of investors' attention. Global gold demand in 2011 was a record $205.5 billion and the price per ounce of gold was very high compared to historical values, indicating a favorable global context for new mining operations.

European countries with significant gold reserves have invested in the construction of modern and efficient gold mining operations. Among the most relevant examples are Turkey, Sweden, Finland and Greece.

Romania's mining strategy for 2008-2020, prepared by the Ministry of Economy and approved by the Romanian Government, foresees that one of the measures to be taken during this period will be the gradual reduction of the role of the state in mining exploration and exploitation activities.

Currently, there are two valid exploitation licenses and seven exploration licenses for gold and silver in Romania, according to data from the National Agency for Mineral Resources: Rosia Montana, Alba - Rosia Montana Gold Corporation S.A. and Certej, Hunedoara - SC Deva Gold S.A.

If the two projects with mining licenses start producing gold, Romania would become the biggest gold producer in Europe. According to the companies involved, annual production at Roșia Montană will be 15 tons of gold and 3 tons at Certej.

The Roșia Montană mining project involves the extraction and concentration by flotation of 3 million tons of gold ore followed by the processing of 420 thousand

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tons/year of gold concentrate for a period of 11 years, together with the storage and management of waste resulting from mining and mineral processing.

2. THE ROȘIA MONTANĂ MINING PROJECT

The Rosia Montana gold mining project is one of the most important investments in Romania in recent years. The project is operated by Rosia Montana Gold Corporation (RMGC), which is a joint venture between the Canadian company Gabriel Resources (76%) and the Romanian state, through Minvest Deva (24%). Mining activity at Rosia Montana dates back more than 2000 years, the most relevant technical aspects can be considered to be those after 1970, a year considered to be a particular milestone in the mining activity at Rosia Montana, the year in which the last major investment was made, the mine operating in this form until June 2006 when it stopped its activity. In 1970, the Cetate quarry was opened and for the first time surface mining began. The opening of the Cetate quarry meant the destruction of the historical monument "Roman Fortresses" Also in 1970 the capacity of the Gura Rosiei processing plant was developed, with a processing capacity of 420 thousand tons of ore per year.

The gold-silver ore processing technology chosen was the flotation concentration of metallic sulphides containing gold and silver, obtaining a gold pyrite concentrate.

The choice was made to open the Cetate quarry instead of the Cârnic quarry, because the agreed technology, in conjunction with the requirements of the regime of the time, managed to solve the social problems of the time. There are certain data relevant to the Rosia Montana deposit.

These data directly influence the technological schemes applicable to the processing of the ore:

-Roșia Montană ores have low grades. High grade zones have been mined for over 2000 years. The revenues that can be recorded per ton of ore are therefore low and the processing method used must involve low operating costs.

-The Rosia Montana deposit is large in size and low in grade. The processing method must allow large quantities to be processed in order to ensure adequate economic benefits and a sustainable project unaffected by changing economic conditions.

-In addition to gold, the ore from Rosia Montana also contains significant quantities of silver. The chosen technological process must also allow for the recovery of silver.

-The ore from Rosia Montana contains sulphides - mainly pyrite. Processes not applicable to sulphide ores cannot be used.

The ores from Roșia Montană contain gold and silver associated with both sulphide and non-sulphide host rocks. A process that treats only the host rock (silicate) or only the sulphides will result in low extraction yields and improper exploitation of the resource. The process must consider both gold and silver host mineralization.

These issues imply several options for the technological process, and the leaching alternatives will be heavily disadvantaged and cannot be applied without test work and economic analysis.

Processes involving high operating costs, such as pressure oxidation of the whole ore and similar complex processes at high temperature and pressure cannot be applied.

Halide leaching alternatives (bromide, chloride, iodide) do not recover silver. Apart from the issues of cost, toxicity and the difficulty of denitrification of the tailings, these leaching alternatives do not allow silver to be extracted at all, this substantial and valuable resource remaining in the tailings.

It is assumed that gold and silver can be extracted from the sulphides by flotation or other recovery processes, but much of the precious metals that are not concentrated in the sulphides will be lost, remaining in the flotation tailings. If the flotation tailings are not also processed, large losses of gold and silver removed with the process tailings will result.

In order to sustain the economics of the project and to continue operation in more unfavorable economic times it will likely be necessary to process all of the ore.

The processing of the entire quantity of ore is necessary to maximize the rational exploitation of the resource at Rosia Montana.

While these conclusions can be drawn by simply analyzing the characteristics of the ore from Roșia Montană, various other variants of supposedly disadvantageous technological processes were evaluated during the processes of choosing the technological scheme, to which several international design companies involved in the development of the project contributed. [1], [3], [5], [8].

2.1. Technological flow

All the gold mining units in Romania before 1989 were included in a technological flow made up of 3 technological segments, the first segment involved the production of gold concentrates from ore, Roșia Montană, Brad - Gura Barza, Certej. The second segment involved the reprocessing of gold concentrates by Merill-Crowe type cyanidation at the Săsar and Baia de Arieș cyanidation plants, obtaining very rich concentrates, respectively 6000-7000g/t Au. The third segment was carried out at Baia Mare, where the concentrates from the cyanidation were metallurgically processed and alloyed. Thus, under conditions of maximum yields planned by research and design for each segment of 75% at Roșia Montană, 80% at Baia de Arieș cyanidation and 95% at Baia Mare, a maximum yield of 57% could be obtained. Under certain real conditions, however, the intermediate yields were less than: 56% Roșia Montană, 75% Baia de Arieș, and 95% Baia Mare, and the final yield was 40%. In simple terms, from 100 kg of gold in the ore at Rosia Montana, between 40-57 kg of gold could be finally obtained in the form of ingot, the rest being found in the tailings ponds of the mining units.

At Rosia Montana, the technology for obtaining gold pyrite concentrates by flotation was designed to have a maximum yield of 75%, ensured by combining the ore from the 5 zones of the Cetate quarry, a breccia zone and 4 dacite zones in the predetermined proportions, so that the sulfur concentration in the ore mixture would be at least 3%, which is necessary for the flotation process.

At Rosia Montana, there was never any question of recovering other chemical elements existing in the deposit in very low concentrations, because it was not economically efficient. All the research studies carried out over the years by specialized institutes have confirmed that only gold and silver are of economic interest to be exploited at Rosia Montana. In Figures 1 and 2 I show the elements with concentrations below the Earth's crust average, respectively the elements with concentrations above the Earth's crust average. [6], [9].

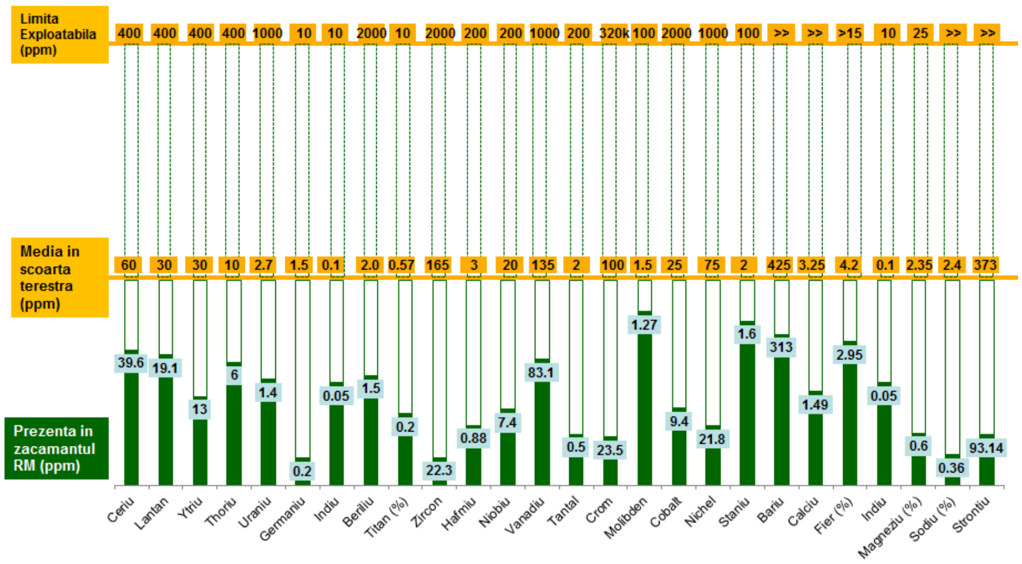

Figure 1. Figure explanation

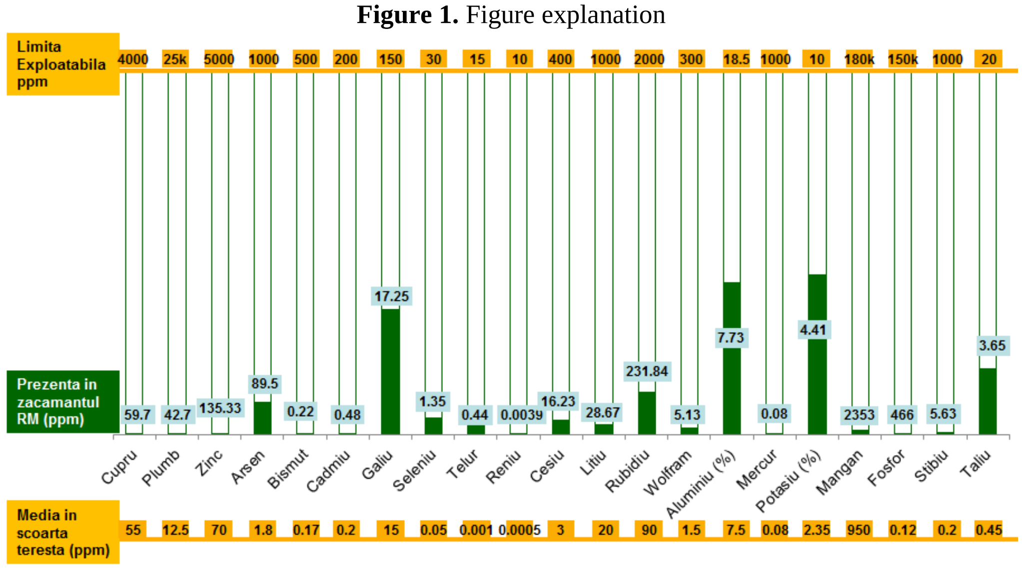

Figure 2. Elements with above-average concentrations in the Earth's crust

Geological prospecting was carried out gradually over time by a specialized unit, IPEG Deva, with the aim of discovering gold-silver ore reserves. The quantity of ore discovered did not exceed 15 million tons. At the ore processing plant, two types of gold concentrates were produced: gold-bearing pyrite obtained by flotation, with a gold content of 20-30g/t, and a low-sulfur gold concentrate with a gold content of 40-60g/t, periodically harvested from specific areas of the plant where free gold concentrated hydro-gravitationally, without any technical control of the process. Additionally, raw gold was obtained by amalgamating very rich sands periodically collected from areas with high centrifugal-gravitational concentration potential, especially from the interior of the ore mills, behind the shields.

The gold concentrates from Roșia Montană were sold for reprocessing by cyanidation at Săsar until 1993, then at Baia de Arieș until 2003 when cyanidation was stopped, and later at Transgold Baia Mare until 2006, when mining activities at Roșia Montană ceased.

The raw gold obtained through amalgamation was always delivered to the final processor for purification.

As mining progressed at the Cetate quarry, changes in the geological characteristics of the ore began to appear (compared to the initial state when the quarry opened), materialized by a decrease in the sulfur content in the ore. This resulted in the recovery of gold concentrates through flotation with increasingly lower yields, with much of the free gold in the ore remaining in the waste, as there was no technological segment for its recovery. Very fine gold (less than 10 microns) could be recovered by flotation, while coarse free gold (over 100 microns) was recovered by gravity or centrifugal methods in the mills. However, the fraction between 10 and 100 microns remained in the waste.

After 1990, mining activities at Roșia Montană continued passively, requiring subsidies to operate due to changes in economic-financial analysis principles. The volume of subsidies amounted to approximately 4 million euros per year, with a subsidization rate of 70%, for an expenditure of 1000 RON per goods production of 2700-3000 RON.

There were also attempts to expand production capacities, one before 1989 with a much larger capacity than the existing one, at the Carpeni processing plant, a project that was not realized due to the change in the system after 1989. Another project aimed to increase the production capacity from 420.000 tons per year to 580.000 tons per year, using the same processing technology, approved by the government in 1995 but not materialized due to lack of funding capacity. Starting in 1997, the national restructuring program in mining began, involving repeated layoffs, which ended in 2006 when mining activities ceased.

2.2. Cyanide Use in Gold Extraction

Over 95% of global mining operations use cyanide as a reagent to recover gold in the technological process. This technology is used by countries with significant environmental concerns, such as Sweden, Finland and the United States. [4], [5].

Cyanide remains the preferred reagent in the extraction of gold and silver, despite extensive research aimed at identifying more benign chemical methods to replace it. The use of cyanide by the world's most sophisticated mining companies continues to confirm that cyanidation is the preferred extraction method. Even in new mining operations and in jurisdictions most concerned about environmental issues, cyanide continues to be selected as the extraction method. In fact, in the vast majority of cases, it is the only practical reagent available for the extraction process. Cyanide is a reagent subject to strict regulations concerning its manufacture, transport, handling, use, neutralization, and waste management in the mining industry.

Only about 13% of the global production of cyanide is used in the mining industry. The industry has over 100 years of experience in selecting safe management techniques, if properly implemented. The results of this experience are integrated into the International Cyanide Management Code, to which Roșia Montană Gold Corporation (RMGC) is a signatory.

Experts have confirmed that the proposed project for cyanide use, detoxification, and subsequent waste management complies with the Best Available Techniques (BAT) as per the European Commission's standards.

RMGC is committed to meeting the strictest performance standards regarding toxicity, which can be achieved given the characteristics of the ore. Performance can be measured and confirmed, with toxicity reaching negligible levels that pose no danger.

RMGC implements proven techniques that have demonstrated viability and applies the most prudent and safest global standards. Moreover, RMGC uses the best detoxification technology to ensure the lowest possible cyanide levels in processing waste.

The strict standard set by EU and Romanian legislation is 10 ppm CNWAD (Weak Acid Dissociable Cyanide), and RMGC has committed not to exceed an average of 5 to 7 ppm CNWAD, measured monthly at the discharge point to the Tailings Decantation Pond (IDS), a level well below the EU directive limit, which takes operational realities into account.

The detoxification tests using the best technology for the ore characteristics at Roșia Montană yielded values ranging from 1 ppm to 1.6 ppm CNWAD.

This proposed project doubled the time required for the detoxification reaction, cyanide oxidation, in compliance with BAT requirements. The reagent systems have additional capacity to account for variations in ore characteristics and to ensure compliance with discharge standards. This ensures total exposure of all waste to the neutralization chemical reaction, which minimizes cyanide concentration and contributes to achieving the best possible result. In these conditions, the cyanide levels resulting from the oxidation process are determined by the ore's characteristics, not by the technology or neutralization method.

Additional natural degradation of cyanide, upon exposure to sunlight, and its dilution within the larger mass of previously degraded material, allows for a second reduced standard of 3 ppm CNWAD in the IDS. International standards vary, with concentrations between 10 ppm CNWAD in the EU, 50 ppm CNWAD in Australia, and even 100 ppm CNTOTAL cyanide in Argentina. These levels are considered safe for animals and birds that may be exposed to the tailings pond area.

3. GEOMECHANICAL CHARACTERIZATION OF ROȘIA MONTANĂ ORE BODY

Laboratory analyses and determinations were carried out on rock samples collected from geotechnical drilling:

- Granulometric analysis of soils;
- Determination of natural moisture (w) and plasticity limit moisture (w_L, w_P);
- Consistency and plasticity indices (I_C, I_P);
- Determination of contraction-swelling behavior of soils (PUCM);
- Compressibility testing for undisturbed soil samples;
- Shear resistance parameters (Φ, c) for undisturbed soil samples.

The results were analyzed and summarized in tables. At the Geotechnical Analysis and Testing Laboratory of the University of Petroșani, physical, mechanical, and deformation properties were determined according to current standards for classification in accordance with the admissibility standards, for use in construction. The potential use of the rocks from excavations for the construction of road infrastructure and for the embankment dam of the tailings pond was also analyzed. [1], [2], [10].

For the use of rocks in infrastructure works and concrete for surface industrial foundation construction, they must meet the SR 667/2001 standard. According to the standard, rocks from quarries are classified into five classes (A, B, C, D, E), depending on intrinsic physical and mechanical characteristics: apparent porosity at normal pressure; compressive strength in dry state; wear resistance using the Los Angeles machine; crushing resistance under dry compressive conditions; freeze-thaw resistance.

The natural stone products used for road infrastructure and concrete must come from igneous, metamorphic, or sedimentary rocks. The rocks must be homogeneous in structure and mineralogical composition, free from visible physical or chemical degradation, devoid of pyrite, limonite, or soluble salts, and free from microcrystalline or amorphous silica that could react with the alkalies in cement.

The geotechnical study for the plant site aims to analyze the geotechnical characteristics of the proposed location, including current conditions, lithology, and properties of the strata, groundwater table location, and recommend the best solutions for the safety of the processing plant's construction.

4. CONCLUSIONS

The Roșia Montană mining project involves the extraction and flotation concentration of 3 million tons of gold ore, followed by the processing of 420,000 tons/year of gold concentrate over 11 years. Waste disposal and management resulting from mining operations and ore processing are required.

All research studies carried out over time by specialized institutes have confirmed that only gold and silver are of economic interest to exploit at Roșia Montană. It was never considered to recover other chemical elements from the deposit in very low concentrations, as it was economically inefficient.

The amount of ore discovered did not exceed 15 million tons. Two types of gold concentrates were produced: gold-bearing pyrite obtained by flotation with a gold content of 20-30g/t and a low-sulfur gold concentrate with a gold content of 40-60g/t. The annual gold production at Roșia Montană could reach 15 tons of gold.

Over 95% of global mining operations use cyanide for gold recovery. This technology is used by environmentally conscious countries like Sweden, Finland, and the USA.

EU and Romanian legislation sets a 10 ppm CNWAD standard for cyanide in acid medium, and RMGC has committed to not exceeding an average of 5 to 7 ppm CNWAD.

The detoxification tests using the best technology for Roșia Montană ore characteristics ranged from 1 ppm to 1.6 ppm CNWAD.

The analyzed rocks fall into class A and we'll be available to be used for mining surface constructions and the infrastructure of land communication routes which will be executed in the road area.

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EXCAVATION OF THE REFUGE INCLINE, BETWEEN HORIZONS +226M AND +190M, THE WESTERN WING, FROM OCNELE MARI ROCK SALT MINE

Dacian-Paul MARIAN [1], Ilie ONICA[2]

Abstract: *The refuge incline between the levels +190m and +226m, was designed and executed as an additional escape way for personnel in the case of possible collapse of the resistance structures. The paper presents synthetically the stability analysis by numerical modeling with finite element of the incline and of the resistance structures at the boundary between the deposit floor and the mining field. Also, the main elements of the refuge incline excavation project by drilling-blasting technology are synthesized.*

Key words: *rock salt, incline, refuge way, drilling-blasting, numerical modeling, finite element*

1. THE GEOLOGICAL CHARACTERISTICS OF THE OCNELE MARI ROCK SALT DEPOSIT

The Ocnele Mari rock salt deposit (fig.1) is found in the area of the subcarpathian hills of Oltenia, stretching from the east of the Olt river to the west of the Govora stream, passing through the territory of the Ocnele Mari locality in Vâlcea county [28].

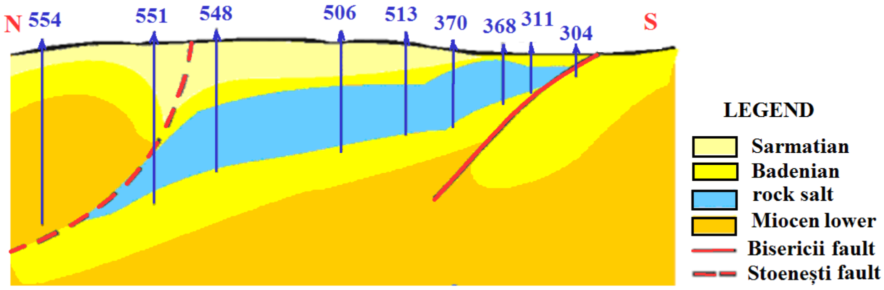

Figure 1. Geological vertical cross-section through the Ocnele Mari rock salt massif

The Cocenesti perimeter is located in the eastern area of the Ocnele Mari deposit. Access to the deposit is on the road that goes to the town of Ocnele Mari, Vâlcea county. The morphology of the region has a hilly aspect, with heights between 250 - 450m.

From a stratigraphic point of view, the Ocnele Mari region includes Paleogene, Neogene and Quaternary geological formations.

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The deposit includes the following geological formations: in the roof of the deposit there are deposits made of yellowish clays, predominantly fine sandy, compact marls, sometimes with friction mirrors, and near the contact with rock salt and anhydrite nests. In the development area of the Sarmatian, the sequence of deposits in the roof of the deposit begins with deposits of clayey sands, fine sandy clays, micafers with white films and intercalations of gray sands.

The Ocnele-Mari rock salt deposit has the shape of an elongated lens in the E-W direction, measuring approx. 7.5 km, and to the N-S approx. 3.5 km, presenting an axial rise in the Ocniţa area, with slopes to the N.

The thickness of the roof deposits varies between 20 and 50 m, in the southern part and up to 700-800 m, in the northern part, with the sinking of the deposit. The thickness of the rock salt deposit is variable, reaching up to the laminations in the north and south, the maximum thickness reaching 450 m, in the central part of the lens.

The rock salt in the deposit has a macrogranular structure with well-developed crystals, grayish white or blackish in color, depending on the contribution of terrigenous impurities. Banks of white rock salt alternate with those of darker rock salt, and in the lower part of the deposit, a bank of black salt with thicknesses from 5 to 30 m, impurized with anhydrite, having a higher hardness and compactness than the rest of the rock salt, frequently appears from the deposit.

The deposits in the floor of the deposit are composed of compact gray marls, stratified, with films of sand on stratification planes, sometimes gray-green.

From a tectonic point of view, the Ocnele Mari rock salt deposit is flanked to the north and south by two major faults, namely: the Stoeneşti fault with the NE direction and dip to the N; the Church fault with the NE direction and dip to the N [20].

From a genetic point of view, rock salt was formed in a halogen pool made up of a series of bays and lagoons. The rock salt was deposited unevenly inside the basin, depending on the intake conditions and the morphology of the bottom of the sedimentation basin, the age of the rock salt from Ocnele Mari - Cocenesti being middle Badenian.

From a macroscopic point of view, the rock salt from Coceneşti - Ocnele Mari is presented in the form of alternating bands of white salt and dark gray or blackish rock salt, impure with films and centimeter fragments of marl or nests of anhydrite.

The mineralogical composition consists mainly of gypsum and anhydrite, in a proportion of 1 - 5% and 0.02 - 0.30% kieserite, and clay and coal minerals in a proportion of approx. 5-35%.

The chemical composition of the rock salt indicates an average content of 99% NaCl and 0.91 – 4.21% insoluble.

The rock salt from the Ocnele Mari deposit is presented in the form of alternations of centimeter-sized banks of white salt, dark gray or blackish salt. Towards the bed of the lens appears a bank of blackish or black salt with a thickness of 5-25 m having a higher hardness than white or gray salt (Prida et al., 2004).

The microscopic analyzes performed on the samples collected from the mining boreholes highlighted, mainly, the following minerals: halite (NaCl), 94.50%; anhydrite ($CaSO4$), 1-5%; gypsum ($CaSO4*2.H2O$) <1 %; kiserite ($MgSO4*H2O$) < 2.5%; schoenite ($K2Mg(SO40*6.H2O$) <7%; clay minerals and coal substances <45%.

2. EXPLOITATION OF THE ROCK SALT DEPOSIT UNDER GEO-MINING CONDITIONS FROM OCNELE MARI

The main workings to open the Ocnele Mari rock salt deposit are the following: the access tunnel, with a total length of 736 m, designed for trucks transport; transverse gallery opening the horizon + 226 m; trucks incline, for opening the horizon +210 m, with the length of approx. 260 m; the transverse gallery opening the horizon +210 m, with the length of approx. 110 m; ventilation shaft no. 1, the western wing, excavated between levels +305.35 and +225.25 m (at the bottom part of the shaft, at the horizon + 226 m, the main fan station is set up); the transport gallery with belt conveyors, between the +253.69 m and +201.49 m levels, which is currently under construction [28].

The mining method used at the Ocnele Mari rock salt mine is the one with small rooms and square pillars, which consists in the excavation through the drilling-blasting technology of the rooms, between which are abandoned parallelepiped pillars with a square base, called inter-rooms pillars [1, 2, 4, 25, 22].

By adopting the mechanized cutting technology with the Sandvik MT 520 roadheader, the use of explosive cutting will be abandoned, also eliminating their destructive effect on resistance structures.

At horizons +210 m, +226 m and +190 m, the mining method with small rooms and square pillars is applied. The tracing network of the mining method is based on the gap (square network) with a side of 30 m, in which the opening (width) of the rooms, respectively the side of the pillars is dimensioned according to the mining depth, so that their sum $(l_c + l_p)$ always be 30 m [11, 32].

Depending on the depth from the surface, the width of the rooms is 15 m (east) 16 m (west), and the pillars 15 m and 14 m. The ceilings thickness between the first exploitation horizons is 8 m and 10 m, between the next two.

3. LOCATION OF THE REFUGE INCLINE

The incline of connection between horizon +190 m and +226 m (fig.2), the western wing has a total length of 410.1 m and is designed to be a way of refuge for personnel and equipment from underground in case of possible damages produced at Ocnele Mari saline [26].

The incline is composed of two segments: the first section has a length of 180.4 m, with a slope of 8.9% (for truck transport); the second section is 229.7 m long, with a slope of 8.7%. The horizontal distance between the planes is approx. 34.5 m, which determined the design of 18 m curvature radii, in the connecting areas with the ceilings, radii that allow dump trucks to enter the curve.

The distance of the incline horizons +190m/+210 m from the limit of the mining rooms from the horizon. +190 m is 5.3m and 7.5m, and the inclined plane horizon. +210 m/+226 m from the limit of the mining rooms from horizon.+226 m is 17.5m.

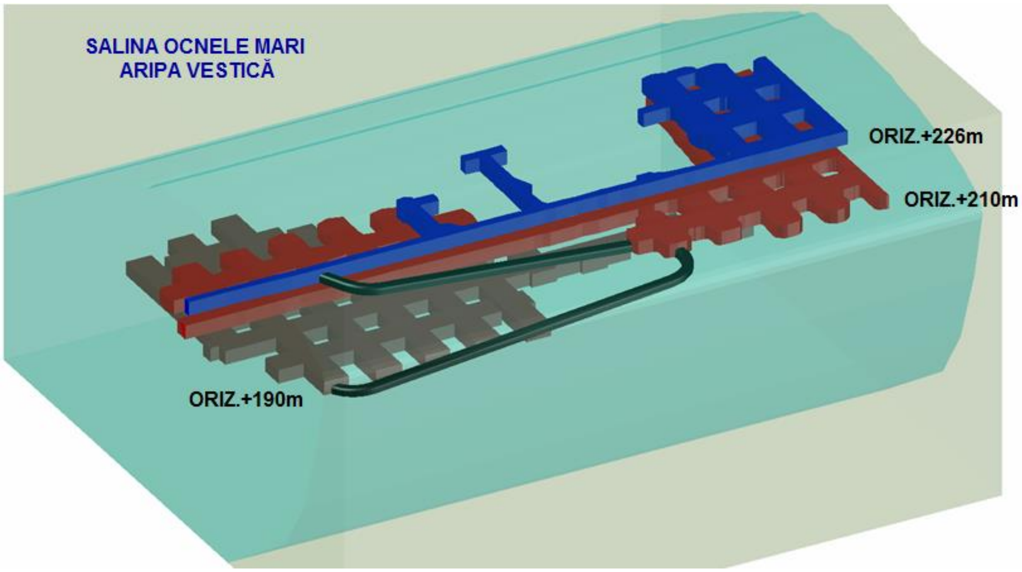


Figure 2. Spatial representation of the incline horizons +190m/226m and of the neighboring rooms

The choice of a cross-section of the incline with a width of 6 m, a height of 5 m and a cross-section of 28.28m^2 (fig.3) was determined by the possibility of digging in optimal conditions of the inclined plane and by the need to evacuate the equipment from underground in case an accident.

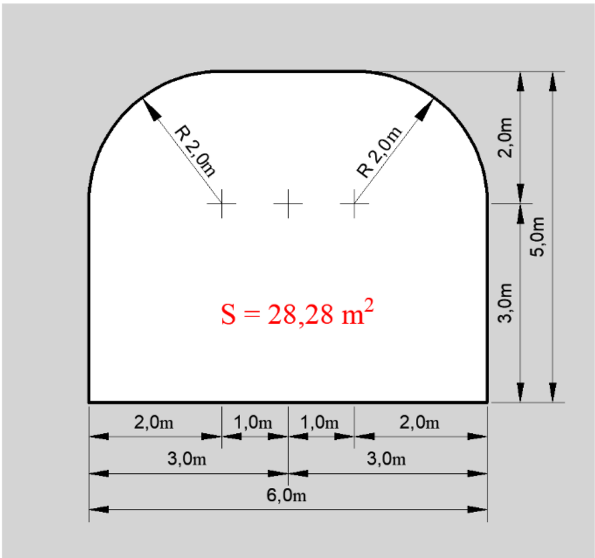


Figure 3. The geometric parameters of the transverse cross-section of the refuge incline horizons +190m/+226m, from Ocnele Mari saline

The spatial positioning of the incline with respect to the exploited areas and in relation to the limit of the deposit in the rocks floor was established following the execution of 11 geological research drillings, from the mining rooms, located at the +190 m horizon level, in order to precisely establish the limit between the rock salt deposit and the rocks in the floor. So that the location of the incline with respect to the boundaries of the deposit and with respect to the exploited areas does not cause a concentration of stresses that endangers the stability of the incline. Thus, avoids its intersection with the sterile rocks in the floor, a situation that would have required support with elements bearing of the incline and implicitly the generation of unjustified expenses [26].

4. FINITE ELEMENT ANALYSIS OF ESCAPE INCLINE STABILITY

The incline horizons +190 m/266 m was modeled in plane strain hypotesis in a vertical cross-section to capture the presence of the horizontal +190 m/+210 m section as close as possible to the pillar between the incline and the mining rooms, which is and the critical situation both in terms of the stability of the inclined plane and the stability of the 7.5 m wide pillar. The position of the incline being variable in space, the vertical cross-section captured the incline +190m/+210m with the height of the excavation floor at +192 m, and the inclined plane +210 m/+226 m, at the level of 224 m. The depth of the excavation fllor, measured from the surface, is 136 m, for the lower inclined plane and 111m, for the upper plane.

In the stability calculations, an elasto-plastic behavior law without Mohr-Coulomb type hardening/hardening was chosen [23, 24, 25].

Carrying out the analysis with finite element in 2D (fig.4), in plane strain deformation (***, 2008), for the models defined above, required the following stages: I) establishing the limits, the area of interest and the discretization the model; II) determination of areas (regions), calculation assumptions and introduction of geomechanical characteristics; III) imposition of boundary conditions; IV) establishing the initial and loading conditions of the model; V) making calculations and storing the results [23, 24].

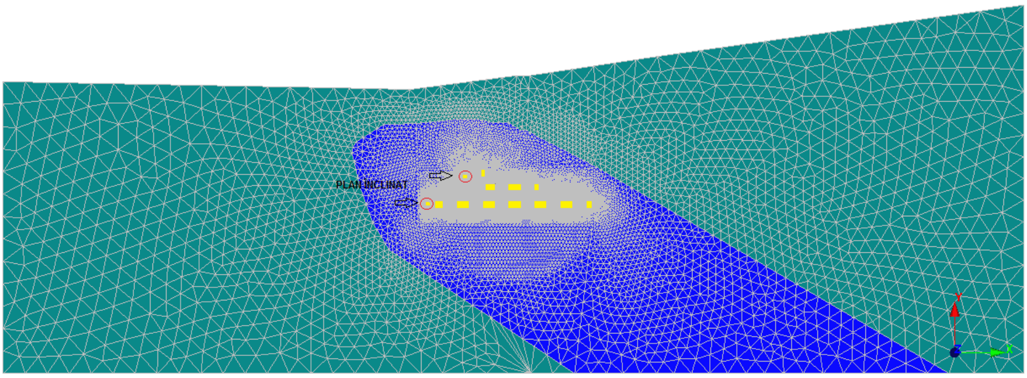


Figure 4. Finite element model discretization of incline stability analysis

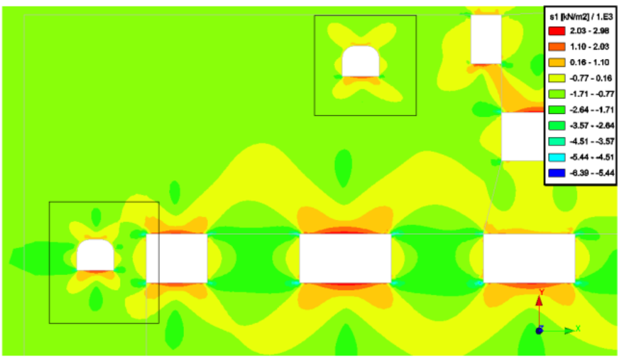
To simplify the 2D numerical model, two regions with specific geomechanical characteristics, corresponding to the surrounding rocks and the rock salt deposit, were considered. The characteristics of the rock salt (mainly), considered homogeneous and isotropic, are presented in table 1 and taken into account with average values, under the hypothesis of elasto-plastic behavior without hardening, of the Mohr-Coulomb type [12, 36].

Table 1. The main average geomechanical characteristics of the rock salt massif and surrounding rocks considered in finite element modeling

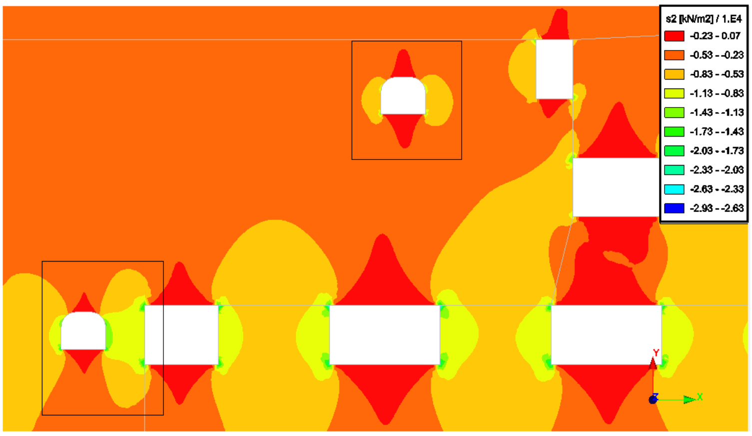
Characteristic	**MU**	**Value**	
		Rock salt	***Surrounding rocks***
Apparent density , ρ_a	kg/m^3	2 150	1900
Apparent specific weight , γ_a	kN/m^3	21,5	19
Elasticity modulus , E	kN/m^2	1 500 000	700 000
Poisson's ratio , ν	adim.	0.25	0.22
Compressive strength , σ_c	kN/m^2	21 700	4 000
Tensile strength , σ_t	kN/m^2	1 200	500
Shear strength , τ_f	kN/m^2	2 300	-
Cohesion , C	kN/m^2	4 000	1 000
Internal friction angle , φ	^{o}	30	18

The initial loading conditions of the 2D model were considered geostatic (Herget, 1988) [9], corresponding to variable thicknesses of the covering formations.

The analysis of the results obtained from the modeling with 2D finite element, respectively the analysis of the stability of the incline at the level of the upper and lower section can be done by comparing the values of tensile, shear and compression stresses calculated on the outline of the excavations with the rock salt strength values, summarized in table 1. The maximum principal stresses and minimum are represented scalar in figure 5.



a)



b)

Figure 5. Principal stresses (a) maximum and (b) minimum, in kN/m^2

A synthetic indicator of the stability of the incline is represented by the safety coefficient calculated according to the Mohr-Coulomb criterion, on the outline of the excavations (fig. 6 and 7). Analyzing the values of the safety coefficients in figures 6 and 7, it can be found an increased stability in the area of the floor and the ceiling of the incline and a lower stability in the area of the walls, especially in the points of intersection of the walls with the floor and the ceiling [26].

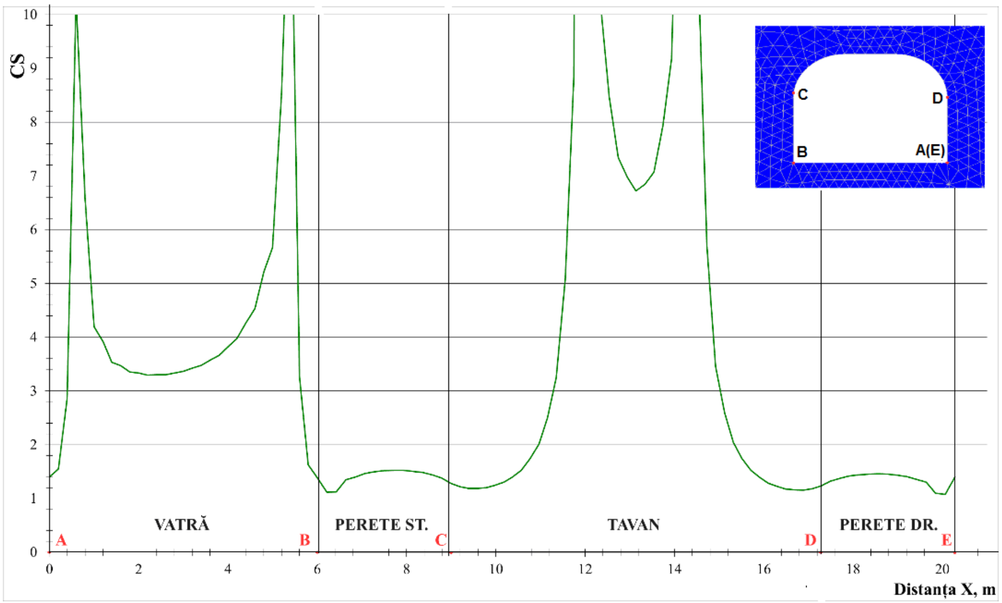


Figure 6. Distribution of the safety coefficient around the incline horizons +210m/+226m

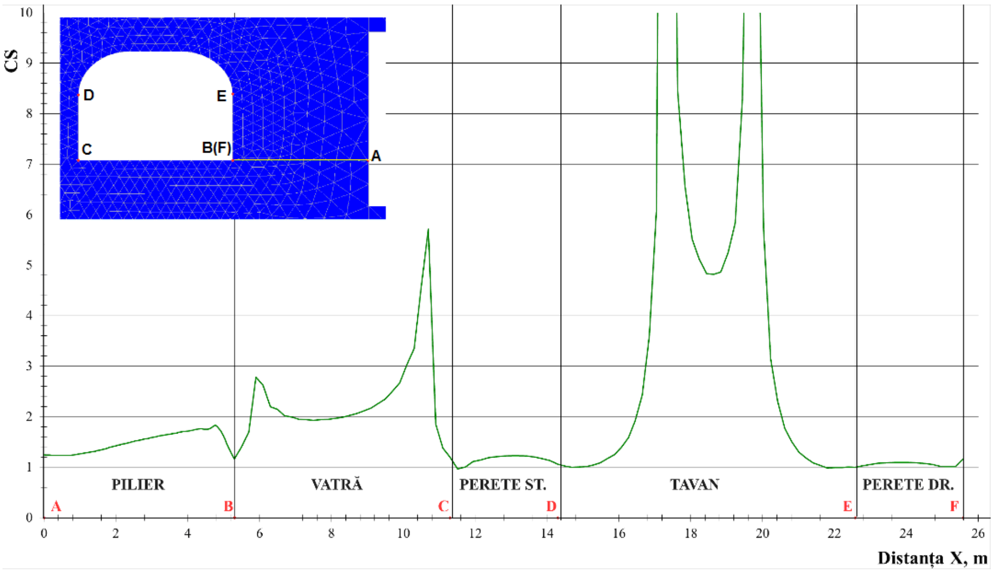
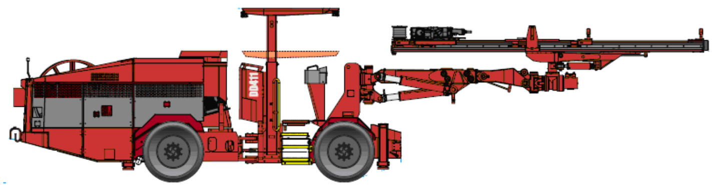


Figure 7. Distribution of the safety coefficient around the incline horizons +190m/+210m

5. DRILLING-BLASTING TECHNOLOGY OF THE ESCAPE INCLINE BETWEEN +190M AND +226M HORIZONS

The following machines and equipment will be used in equipping the drilling-blasting excavation technology: SANDVIK DD411 jumbo (fig. 8.a); Ural-33 chain saw machine; the KOMATSU WA380-8EO wheel loader (fig.8.b); VOLVO A30G dump truck (fig. 8.c); JLG auto nacelle; GAV -1000 fan of 9 kW.



a)

b) c)

Figure 8. The machines in the digging front:
a) SANDVIK DD411 jumbo; b) KOMATSU WA380-8EO wheel loader;
c) VOLVO A30G dump truck

Excavation using the drilling-blasting technology of the incline +190m/+226m is carried out by detonation with explosives placed in ordinary mine holes, in steps of 1.6 m (the drilling-blasting scheme is shown in fig.9.

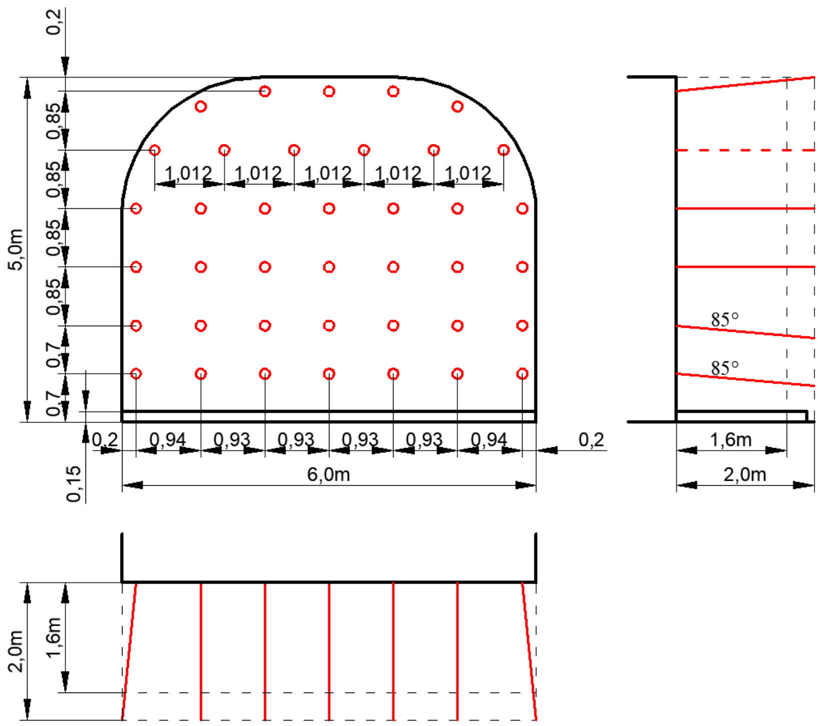


Figure 9. Drilling holes placement scheme for digging the incline

The charging of the holes and the triggering of the explosion is carried out after cutting with the help of the URAL-33 chain saw machine a bottom cut at the floor of the mining working, with a depth of 1.9 m and a thickness of 0.15 m, the charging of the holes and the blasting follow. Then, after ventilation and scaling the ceiling and walls of the excavation, the technology continues with the evacuation of the crushed material with the KOMATSU WA380-8EO front loader (bucket volume of 4m^3), loading into VOLVO A30G dump trucks (bucket volume of 17.8m^3) and transportation of rock salt over a distance of 850 m, measured from the bottom of the incline, to the underground warehouse rock salt from horizon +190 m, rooms 7 W / 35 E [18. 19].

The simple process of excavating the refuge incline +190m/+226m, according to this technology, includes the following technological phases: 1) bottom cut; 2) drilling mine holes; 3) explosive charging of mine holes; 5) ventilation the front after the operation of blasting the holes; 6) scaling the ceiling and walls; 7) evacuation, loading and transport of rock salt detached from the front [15, 16].

The explosive used is RIOMAX XE (MAXAM) in the form of 200 g cartridges, with a length of 200 mm and a maximum diameter of 32 mm, initiated with millisecond delay detonator MM SED 30 ms, arranged in 6 delay intervals (starting from the floor to the ceiling). The nominal diameter of the holes is 40 mm, and the length of the holes varies between 2.0 m and 2.07 m, depending on the inclination of the holes to the front (fig.7). According to the drilling-blasting monograph [3, 5, 6, 13, 17, 33, 34], the main parameters, for a step of advancement, are the following: the total amount of explosive, 34 kg; the specific consumption of explosive, 0.349kg/t, total hole length, 78.75m, 0.809m/t. When advancing the front by one step, a quantity of 97.283 t of rock salt is obtained.

The partial ventilation of the sections of the incline connecting the horizons +190m and +226m are made in a forced draught system, on the lengths of 180.4m (between horizon +226 m and +210 m) and 229.7m (between horizon +210 m and +190 m), designed in accordance with the regulations in force [7, 8, 21]. In the above conditions, the GAV -1000 fan was chosen, which is part of the Ocnele Mari Saline, with the following nominal parameters: fan flow rate, 1,000 m^3/min; fan depression, minimum 63.8 mm H2O; engine power, 9 kW; supply voltage, 380V; diameter of ventilation column, 1 000 mm [26].

The technical-economic indicators were designed [27, 29, 30] for a step advance of 3.2m/day, respectively 2 cycles/day (table 2).

Table 2. The main technical and economic indicators for digging the incline horizons +190m/+226m

Specification	**MU**	**Value**
Total length	m	410.10
Cross section	m^2	28.28
Rock salt reserve	t	24 935.00
Construction time	months	6.15
Duration of a production cycle	hours	6.00
Number of man·shifts per cycle	man·shift/ per cycle	3.67
Productivity	m/man·shift	0.44
Total unit cost	lei/m	3 034.78

6. CONCLUSIONS

The refuge incline between the horizons +190m and +226m was required as an additional way of escape for personnel, in the conditions that there would be a failure of the resistance ceilings between the mining levels that would stop the evacuation of personnel on the opening mine workings.

The placement of the floor rocks of the deposit, due to the proximity of the floor deposit, required geological research boreholes to accurately establish the floor plane and not intersect the waste rock with the incline.

Due to the proximity of the incline to the exploited rooms from the +190m, +210m and +226m horizons, a stability analysis of the pillars between the incline and the rooms was carried out, by numerical modeling with finite element in 2D.

The technology chosen for digging the incline was by drilling-blasting, specific to the execution of horizontal and inclined mining workings at Ocnele Mari rock salt mine.

The calculated technical-economic indicators for digging the refuge incline are favorable, taking into account the valorisation of the obtained rock salt reserve, resulting in a net benefit at the level of the saline of over 2.5 million lei.

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ANALYSIS OF PROTECTED AREAS IMPACTED BY MINING PERIMETERS IN THE BAIA MARE REGION

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Abstract: *The closure of mining activities in Romania, particularly in the Maramureș region, has left a lasting environmental legacy that intersects with protected areas such as Someșul Inferior and Bozânta. This paper explores the ecological, social and structural impacts of mining legacies on protected areas, focusing on challenges such as acid mine drainage, heavy metal contamination and habitat degradation. Key mining site case studies highlight the persistent risks posed by abandoned infrastructure and insufficient rehabilitation efforts. The study highlights the need for robust policy measures, ecological restoration and community engagement to mitigate these impacts and to promote sustainable management of protected areas and resources.*

Key words: *Mining Closure, Acid Mine Drainage, Environmental Impact, Natura 2000, Protected Areas, Biodiversity Conservation*.

1. INTRODUCTION

The establishment of protected areas in Romania has followed a problematic trajectory, characterized by rapid expansion without adequate consideration of existing industrial activities or comprehensive economic impact assessments. This approach has created significant challenges in regions with historical mining activities, particularly in Maramureș, where centuries of mineral extraction have left an enduring environmental legacy.

The mining industry in Maramureș represents one of Romania's most significant historical mineral extraction regions, with documented activities dating back to the 14th century. The region's complex geology has facilitated the extraction of diverse mineral resources, including gold, silver, lead, zinc, and copper, creating a multifaceted environmental challenge that persists long after mining operations have ceased.

Recent environmental protection initiatives, particularly following Romania's accession to the European Union in 2007, have led to the designation of numerous protected areas throughout the country. However, the apparent random delineation of these protected areas has created significant obstacles for both environmental conservation and economic activities. Many protected areas now encompass, or border former mining sites severely affected by acid mine drainage (AMD) [1][2] and heavy metal contamination, creating a fundamental contradiction between conservation objectives and environmental reality.

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Environmental rehabilitation works within these protected areas face additional complications due to stringent conservation requirements, while Romanian environmental protection legislation continues to struggle with inconsistencies. The declaration of Romania's entire territory as a sensitive area remains largely rhetorical, failing to translate into effective environmental protection measures. [3]

1.1. Historical Mining Context

The Maramureș mining district has created an extensive network of underground workings, waste dumps, and processing facilities throughout its operational history. According to researchers, the total volume of underground voids in the region exceeds 50 million cubic meters. These abandoned mining spaces now present significant environmental and safety risks, including ground instability, acid mine drainage, and heavy metal contamination of soil and water resources.[4]

Mining activities in the region have historically focused on polymetallic ore deposits, with extraction methods evolving from primitive surface workings to sophisticated underground operations. This evolution has left a complex legacy of environmental challenges, including:

- **Acid mine drainage**. Historical mining practices, particularly those predating modern environmental regulations, have created extensive networks of underground workings that continue to generate acidic discharge with high concentrations of dissolved metals.[5]
- **Waste processing impacts**, with substantial quantities of material generated during ore processing. Estimates suggest over 44 million tons of tailings have been deposited in the Bozânta facility alone, impacting surrounding ecosystems through direct contamination and wind-borne dispersion of particles.[1]

1.2. Regulatory Framework

Romania's integration into the European Union necessitated significant changes in environmental protection measures. The current regulatory framework encompasses multiple layers of legislation, including:

- **The Environmental Protection Law**, which establishes fundamental environmental protection principles and requirements. This legislation introduced stricter environmental impact assessment procedures and enhanced provisions for public participation in environmental decision-making.[6]
- **The Mining Law**, providing specific regulations for mining activities, including closure and rehabilitation requirements. This legislation emphasizes the importance of environmental protection during all phases of mining operations, from exploration to post-closure monitoring.[7]
- **Natura 2000 requirements**, which add another layer of environmental protection, often overlapping with existing mining areas. Recent assessments by the European Environment Agency 2024 highlight the complex management challenges arising from conflicts between conservation objectives and persistent mining-related pollution.

2. CURRENT STATE OF THE PROBLEM

2.1. Bozânta natural protected area (ROSCI0302)

The Bozânta protected area (Figure 1), classified as a Site of Community Importance (SCI) under the Natura 2000 network, spans 70.4 hectares and was designated in 2016. Its primary purpose is to safeguard two types of natural habitats. However, the Bozânta SCI faces significant ecological challenges due to multiple pollution sources, which threaten the integrity of the habitats it aims to protect.[8]

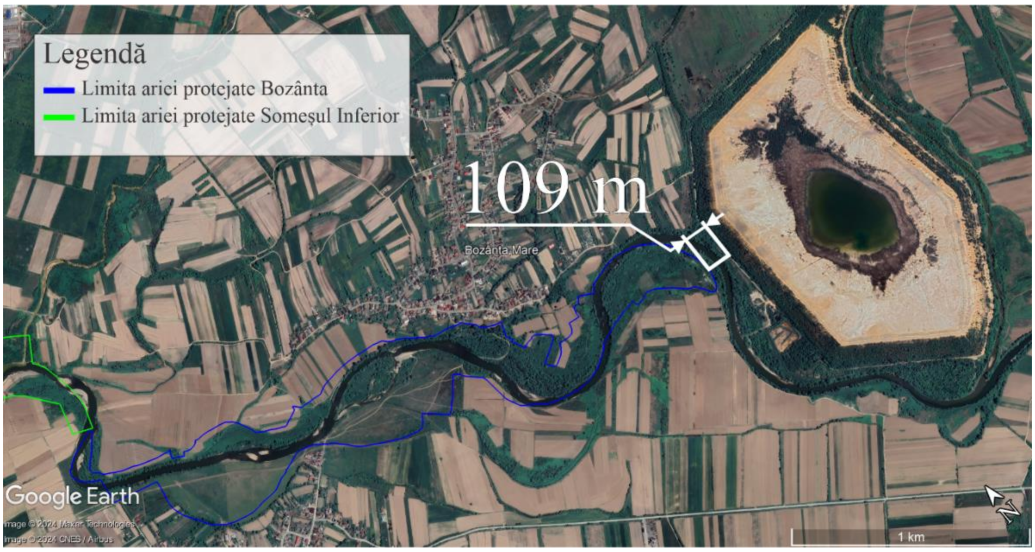

Figure 1. The protected natural area Bozânta (ROSCI0302) and its limits [9]

Among these sources are abandoned mines such as Băița and Săsar, as well as mines considered to have undergone ecological restoration, such as Herja. Additionally, the presence of large tracts of contaminated land used for waste disposal exacerbates the problem. Key pollution hotspots include the Bozânta tailings pond, Central tailings pond, Tăuții de Sus tailings pond, the concentrate depot on Oborului Street, and adjacent areas of former industrial facilities like the Central Flotation Plant.

2.1.1. Pollution Challenges in the Bozânta Protected Area

The Bozânta tailings pond (Figure 2), located just 109 meters from the boundary of the protected area (Figure 1), is a major source of contamination. This pond covers 67 hectares and holds approximately 44 million tons of toxic mining waste.

The waste materials, ranging from clay-sized particles to sandy fractions, contribute to widespread pollutant dispersion. [1]

Figure 2. Bozânta Pond

The accumulated dust on the pond's surface is toxic, containing crystalline silica and heavy metals such as lead (Pb), zinc (Zn), copper (Cu), cadmium (Cd), arsenic (As), manganese (Mn), and others. Wind disperses this dust over adjacent lands, while finer particles are transported over significant distances, posing a severe threat to the environment and public health.[10]

Acidic water continuously seeps from the pond into the Săsar and Lăpuș rivers. Ideally, this water should undergo treatment before discharge, but malfunctioning and inactive collection and treatment systems allow pollutants to flow untreated into the Lăpuș River. This has long-term consequences, degrading water quality and jeopardizing the ecosystems of downstream protected areas.

Figure 3. The raveration phenomenon

From a structural perspective, the Bozânta tailings pond exhibits significant physical instability. Materials have been deposited at a slope angle of at least 18°, promoting erosion (Figure 3) and the release of materials into nearby watercourses. This instability is exacerbated by the absence of functional reverse wells, the last of which failed in 2017—just one year after the protected area was designated. This failure resulted in the release of an estimated 250,000 m³ of water and flotation tailings, including fine particles and inactive sulfides from the pond. Once exposed to environmental factors, these sulfides become reactive, generating acid drainage and contributing to extensive downstream pollution.[11]

2.1.2. Case Study: The Nistru Mine

The Nistru Mine presents challenges regarding the management and treatment of mine water. Although equipped with a treatment plant featuring six basins for neutralization, sedimentation, and toxic sludge separation (Figure 4), the system has been abandoned. Instead, a rudimentary and ineffective setup using only two plastic tanks (Figure 5) is employed. In these tanks, lime milk is prepared and poured directly into mine water at the gallery entrance.

Figure 4. The Nistru Mine and the non-functional treatment plant

Figure 5. Preparing milk of lime and releasing it in the emissary

The resulting neutralization precipitate is left untreated (Figure 6) and discharged directly into local watercourses, bypassing the 2004 Technical Normative for waste storage. Polluted waters flow into the Valea Roșie stream, which merges with the Băița River and eventually reaches the Lăpuș River (Figure 7). The confluence with the Lăpuș River occurs near a protected natural area, amplifying the negative impact on aquatic biodiversity and ecosystem quality. The pollution ultimately propagates to the Someșul Inferior protected area, highlighting the interconnectedness of these ecosystems.

Figure 6. The precipitate that forms after the addition of milk of lime

Figure 7. The confluence area of the Baița river with the Lăpuș river located in a protected area

This situation demonstrates negligence in implementing environmental protection measures and mine water management. The replacement of a comprehensive treatment system with an improvised and inefficient process not only fails to address pollution but exacerbates it. Toxic metals and precipitates contaminate local and protected hydrological networks, endangering flora, fauna, and the health of downstream communities.[13]

2.1.3. Case Study: The Săsar Mine

The Săsar Mine, once benefiting from an economically favorable context due to its valuable deposits, was closed without a coherent national strategy for managing natural resources. The mine's closure, similar to other perimeters in the region, led to the abandonment of significant ore deposits now exposed to infiltration and erosion caused by water. The extracted ore from the Săsar Mine contained substantial quantities of gold, silver, sulfur, bismuth, cadmium, antimony, and quartz, highlighting the unexploited economic potential.

After the cessation of mining operations, no water treatment station was established at the Săsar Mine to handle acid mine drainage (AMD). Field observations indicate that these AMD waters, rich in metallic and mineral pollutants, are discharged uncontrolled into the Săsar River (Figure 8). Metallic precipitates form along the drainage channels, and during heavy rainfall, these precipitates are washed away into the river, amplifying the negative impact on water quality and the surrounding environment (Figure 9).[11]

Figure 8. Water coming from the Săsar mine

Figure 9. The confluence area of the waters from the Săsar mine with the Săsar river located in a protected area

2.1.4. Case Study: The Herja Mine

The Herja Mine, a significant component of the Maramureș mining basin, underwent a decommissioning and ecological restoration project after mining activities ceased. The project aimed to minimize environmental impact and place the area under a passive conservation regime. However, the implementation of the ecological restoration raised persistent technical and environmental issues.[1]

The project included blocking the Herja tunnel, which connected the Central Flotation Plant and the Herja mine, with concrete dams. These dams led to water filling the excavated spaces up to the +380m horizon, where the Ioachim coastal gallery and a treatment plant were constructed (Figure 10). However, the dam material proved unsuitable for long-term resistance in aggressive environments characterized by acid drainage from reactivated polymetallic sulfides in the excavated spaces. Additionally, the area's fractured, faulted rock structures further destabilized the tunnels and dams (Figure 11), allowing uncontrolled discharges into the Săsar River (Figure 12). These discharges eventually impact nearby protected areas. [11]

Figure 10. The Herja mine treatment plant

Figure 11. Mine water entering through the dike of the Herja tunnel

Figure 12. The confluence of the waters coming from the Herja tunnel, the Central Flotation, the Central pond, the Tăuții de Sus pond

2.1.5. Case Study: Central Tailings Pond and Tăuții de Sus Tailings Pond

The Central (Figure 13) and Tăuții de Sus (Figure 14) tailings ponds are located in urbanized areas with expanding communities. For the Central Tailings Pond, Romaltyn Mining S.R.L. holds a license for a project involving the relocation of materials to the Aurul tailings pond, followed by the ecological restoration of both sites. However, local authorities have blocked the project, leaving associated risks unresolved.[14]

In contrast, while rehabilitation efforts began at Tăuții de Sus, they were abandoned at an early stage. The pond's slope shows significant physical instability, while its concave top favors water accumulation, leading to chemical instability due to sulfur presence. These sulfurs, in contact with water and atmospheric oxygen, generate oxidation reactions that produce acid drainage. Acidic water percolates through the pond's foundation, contaminating groundwater, while the remaining water flows into the Săsar River, ultimately impacting the Bozânta and Someșul Inferior protected areas.[15]

Figure 13. Central Tailing Pond

Figure 14. Tăuții de Sus Tailing Pond

2.1.6. Case Study: Central Flotation Plant

This industrial site was managed carelessly and irresponsibly, leaving behind considerable quantities of concentrates and ores in various stages of processing – either raw or crushed and ground (Figure 15) – which were spread over the entire surface of the site. The affected area is extensive, and the land is contaminated with heavy metals. In some places, concentrations of heavy metals (such as iron or zinc) exceed legal limits by more than 1,000 times, posing a major risk to the environment and public health [11].

Also, there are platforms on which significant amounts of ore concentrates were deposited and abandoned, the first platform is Flotația Centrală (Figure 16), and the other platform is on Oborului street (Figure 17), the concentrates were sold but without solve problems of this contaminated area. To date, no adequate measures have been taken to isolate or protect these platforms against environmental factors. Contaminated water from these land surfaces flows into the river Săsar (Figure 12). [12]

This situation highlights an acute lack of compliance with environmental regulations and a profound negligence in the management of industrial waste. Massive heavy metal contamination, such as lead, cadmium and arsenic, endangers local ecosystems and can affect the health of nearby communities, exposing them to risks of chronic toxicity.

Figure 15. Concentrates stored on the Central Flotation land

Figure 16. Mining concentrates stored on the surface of the land from Central Flotation

Figure 17. The area of land on which mining concentrate has been deposited

2.2. Someș Inferior natural protected area (ROSCI0436)

The Someșul Inferior site (Figure 18) is classified as a protected natural area of community interest under the Natura 2000 network, covering an area of 2,969 hectares. Designated in 2016, this site aims to safeguard a unique habitat, 10 species of fish, 2 species of amphibians, and 1 species of mammal. [8]

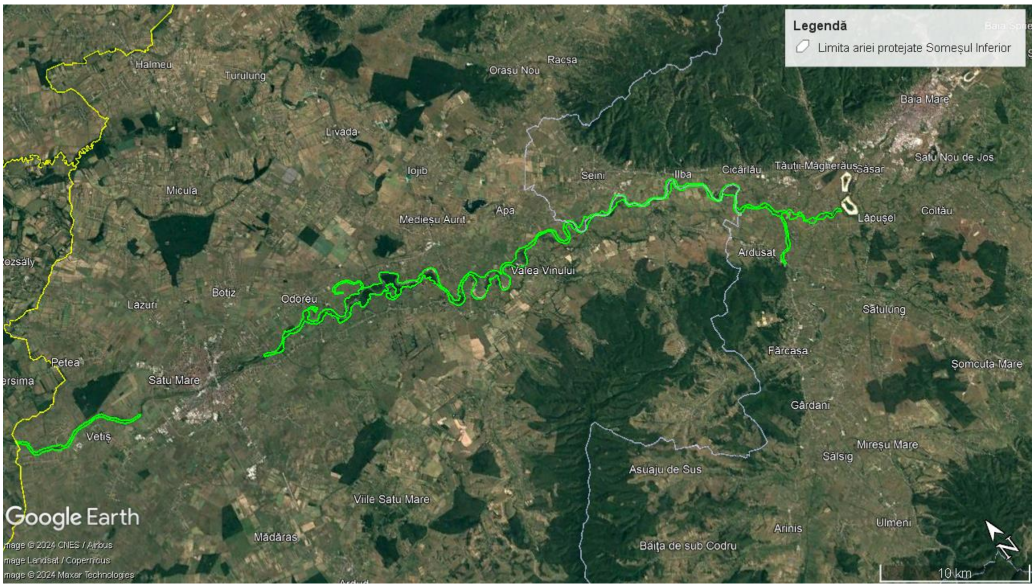

Figure 18. The protected natural area Someș Inferior (ROSCI0436) and its limits [9]

However, the intensive exploitation of natural resources in the Baia Mare mining basin has left behind a severe ecological legacy, characterized by significant quantities of hazardous waste and acid mine drainage (AMD). One of the main contributors to pollution in this protected area is the Ilba mine, along with all the other sources of pollution that flow into the Bozânta protected natural area. [16]

Despite being equipped with a treatment plant at the Asecare gallery entrance, the Ilba mine faces persistent challenges due to malfunctioning water treatment systems and the absence of an authorized hazardous waste disposal site. As a result, contaminated water is frequently discharged into the Valea Colbului stream (Figure 19) and subsequently into the Ilba River. This recurring pollution significantly degrades water quality and the surrounding environment, affecting soil, water, fauna, and flora. Over time, this situation risks causing irreversible damage to local ecosystems and compromising public health.

Downstream from the Asecare gallery lies the Purcăreț gallery (Figure 20), equipped with a reservoir to collect mine water, which is then directed into the Ilba River. However, polymetallic sulfides remaining in the excavated spaces of the mines reactivate upon exposure to environmental factors, generating the acid mine drainage.

These complex chemical processes transform underground and surface waters into a "toxic cocktail" containing metals such as lead, cadmium, arsenic, copper, zinc, and other hazardous substances. These untreated waters are discharged into the downstream ecosystem, eventually impacting the Someșul Inferior protected area (Figure 21). [13]

Figure 19. Mine waters leaving the treatment plant

Figure 20. The accumulation pool at the Purcăreț gallery

Figure 21. The confluence area of the Ilba river with the Someș Inferior protected area

The ecological impact of this phenomenon is severe, affecting both the biotic and abiotic components of the protected site. Aquatic flora and fauna in these ecosystems are exposed to high toxicity levels, leading to bioaccumulation that threatens native and migratory species alike. Chemical pollutants alter water quality, reduce biodiversity, disrupt natural ecological cycles, and impair habitat productivity. [16][17]

Furthermore, abiotic factors such as soil and sediments are also severely impacted. The deposition of metallic precipitates in sediments results in long-term substrate contamination, making ecological rehabilitation extremely challenging and expensive. Groundwater is at risk of contamination through infiltration, posing additional threats to potable water resources for downstream communities.

3. IMPACT OF MINING ON PROTECTED AREAS

The exploitation of mineral resources in the Baia Mare mining basin has caused a range of ecological problems, directly impacting the health of the environment and protected ecosystems, with significant consequences for the region's natural protected areas. The primary cause of acid formation in the context of acid mine drainage is the oxidation of sulfide minerals such as pyrite and marcasite. This chemical process releases reactive hydrogen ions (H^+) along with significant amounts of iron and sulfur. If the balance between acid production and neutralization capacity, whether natural or anthropogenic, is maintained, pollution remains confined to a limited area. However, when the acid-generating potential of reactive materials exceeds the neutralizing capacity of the environment, acid drainage occurs. This process is characterized by the release of acidic compounds into the surroundings, where a highly acidic environment increases the solubility of heavy metals [1].

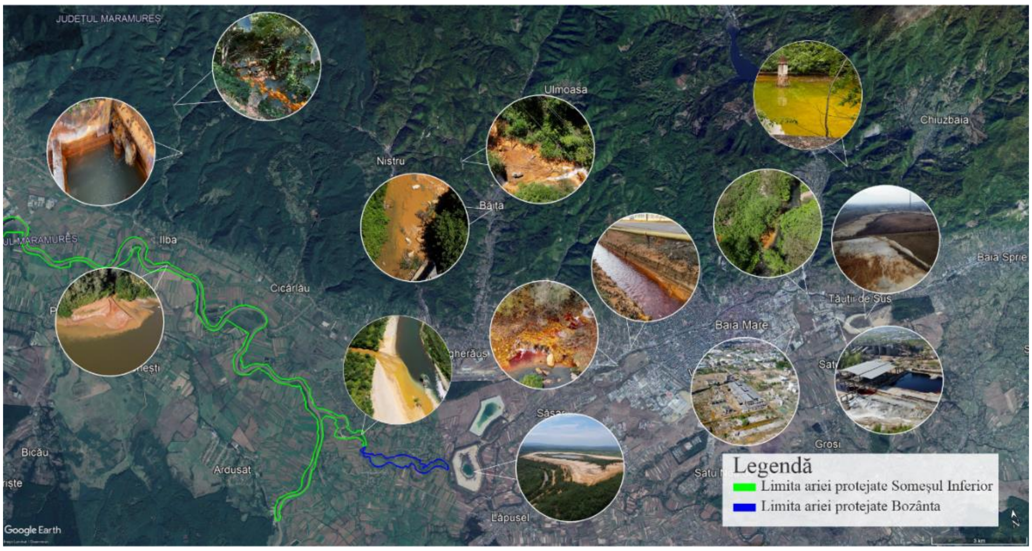

Figure 22. Pollution sources of the two protected areas [9]

The pollution sources affecting the Bozânta (ROSCI0302) and Someșul Inferior (ROSCI0436) protected areas include the Herja, Săsar, Băița, and Ilba mining perimeters, as well as the Bozânta, Central, and Tăuții de Sus tailings ponds, and the land used for storing mining concentrates (Figure 22). The primary form of pollution from these sources is acid drainage, which has profoundly negative impacts on the ecosystems of these protected sites, affecting both biodiversity and the ecological balance of the region. The substantial volume of polluted water draining from these sources represents a grave issue and a paradox in water resource management: while many communities face shortages of potable water—a vital resource—these polluted waters are superficially neutralized with lime, without implementing efficient and sustainable treatment measures. This practice not only perpetuates pollution but also disregards the strategic value of clean water, endangering both protected ecosystems and the communities that depend on them.[18]

3.1. Heavy Metal Pollution and Water Acidification

One of the primary effects of mine water on protected areas is contamination with heavy metals and water acidification. These waters often exceed permissible levels of heavy metals, including polymetallic sulfides, which, when exposed to oxygen and water, generate sulfuric acid. This acid reacts with surrounding minerals and rocks, dissolving them and releasing heavy metals such as lead, cadmium, arsenic, and copper, which accumulate in water and soil. In the case of mine water from unrehabilitated mines, acid drainage becomes an ongoing issue, with devastating effects on local flora and fauna.[19]

In protected areas like Someșul Inferior and Bozânta, contaminated waters pollute waterways such as the Săsar and Lăpuș rivers, severely affecting water quality. The heavy metals in acidic water are not only toxic to aquatic organisms but also have a bioaccumulative effect, being absorbed by organisms in the food chain. As a result, animals and plants in these ecosystems can accumulate heavy metals in their bodies, leading to population declines among protected species and human health risks from the consumption of contaminated water and food products.

3.2. Physical Instability of Tailings Ponds and Ecosystem Risks

Another significant factor contributing to the impact of acid drainage on protected areas is the physical instability of tailings ponds and mine waste dumps. In addition to the water discharged from the body of these ponds, the material deposited on their surface is also released, contributing to the negative impact on the environment. For example, the Bozânta tailings pond, located only 109 meters from the boundary of the Bozânta protected area, is a major source of ongoing pollution. Deposited on a slope with a minimum angle of 18º, the material is unstable and prone to being released into the environment through erosion.[20]

Therefore, the material flows into the Săsar and Lăpuș rivers, contaminating downstream water sources and affecting protected ecosystems in these areas. This phenomenon not only degrades water quality but also reduces the ability of ecosystems to support aquatic life, including rare and protected species. Additionally, the Bozânta, Tăuții de Sus, and Central tailings ponds, which contain fine-grained mining waste, generate sclerosant dust, with fine particles carried by the wind to adjacent lands.

3.3. Soil Contamination and Biodiversity Risks

In addition to water impacts, mine water has a negative effect on the soil in protected areas. Precipitation formed after pH adjustment and materials transported by wind contaminate the soil with heavy metals, altering its structure and fertility. This reduces the soil's ability to support vegetation, directly affecting protected plant species in these areas.

The impact on vegetation and wildlife is that soil acidification affects plant species sensitive to pH changes, reducing vegetation diversity and destroying habitats for various animal species. Furthermore, polluted soil and water create a negative interdependence between abiotic factors (water and soil) and biotic factors (flora and fauna), with long-term consequences. For example, plants exposed to heavy metals may lack essential nutrients or accumulate toxic substances, affecting herbivores that feed on them.

3.4. Public Health Risks

The contamination of water and soil with heavy metals poses significant risks to human health. Residents of affected areas, especially those reliant on natural resources for drinking water and agriculture, face risks of heavy metal poisoning. Mine water entering rivers that traverse these protected areas may be used by local communities for irrigation or even as a source of drinking water, increasing the risk of contamination of the food chain and drinking water.

Public health risks include direct exposure to sclerosant dust and airborne heavy metals, leading to respiratory illnesses and other long-term health problems. These risks are amplified by the lack of effective waste and mine water management in the region.

3.5. Policy and Governance Challenges

The impact of mining on protected areas is exacerbated by inadequate policies, fragmented governance, and insufficient enforcement of environmental regulations.

Romania's environmental regulations, while comprehensive on paper, lack clear mechanisms for enforcement and accountability. For instance, Government Decision No. 188/2002 declaring Romania a sensitive area has yet to translate into effective pollution control measures. The absence of integrated policies for managing mining legacies and protected areas leaves a gap in addressing the root causes of ecological degradation.

Although several ecological restoration projects have been initiated, their implementation is often hindered by technical shortcomings, limited funding, and political obstacles. In cases like Mina Herja, poorly designed restoration measures have exacerbated environmental risks instead of mitigating them.

The overlap of responsibilities between local authorities, national agencies, and private stakeholders creates bureaucratic delays and inefficiencies. A lack of collaboration undermines efforts to develop holistic solutions, leaving protected areas and communities vulnerable to ongoing and future challenges.

The pollution of protected areas, along with other regions, by heavy metals has lasting consequences that inevitably affect human health. Recent studies emphasise the significant risks linked to extended exposure to heavy metals, revealing their serious and sometimes permanent effects on human health. Extended exposure to these hazardous compounds, frequently present in polluted water, soil, and air, has been associated with many severe health issues. Concerning consequences include neurological problems such as cognitive impairment, developmental delays, and neurodegenerative diseases like Alzheimer's and Parkinson's. Moreover, cardiovascular health can be substantially affected by exposure to heavy metals. Research indicates that metals like arsenic and cadmium correlate with hypertension, atherosclerosis, and an elevated risk of myocardial infarction and cerebrovascular accident. The consequences are believed to stem from oxidative stress and inflammation caused by metal accumulation in vascular tissues, resulting in the gradual decline of cardiovascular function. Carcinogenic metals, including chromium, nickel, and arsenic, disrupt DNA repair processes and provoke genetic changes, facilitating the proliferation of malignant cells. The International Agency for Research on Cancer (IARC) has designated certain heavy metals as category 1 carcinogens, underscoring their capacity to induce substantial harm.[21][22]

4. CONCLUSIONS

This situation highlights the absence of essential post-closure measures needed to prevent and mitigate pollution effects resulting from mining activities. It also reflects poor management of closed mining perimeters, exacerbating environmental degradation, increasing public health risks, and deteriorating local ecosystems. The issue of underground cavity collapses emphasizes the need for appropriate backfill materials with chemical buffering properties capable of limiting pollutant reactions.

Adopting a coherent environmental policy and initiating rehabilitation projects are imperative to halt further environmental degradation and harness the economic and ecological potential of the region. Utilizing inert materials from waste heaps or tailings ponds, mixed with zeolite, could significantly contribute to stabilizing mining voids, provided that residual minerals are first recovered from these materials.

In light of rising metal prices, a detailed analysis of the feasibility of reopening and recovering abandoned mineral resources, both below and above the base level, is necessary. After extraction, the resulting spaces could be effectively backfilled, contributing to the structural stability of the subsurface and freeing up significant land areas in the Baia Mare metropolitan zone. These measures would not only mitigate risks associated with mining voids and pollution but also support the region's sustainable development, integrating resource recovery with environmental and community protection.

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STUDY OF THE PILLARS IN THE VICINITY OF THE VICTORIA MINE - SLĂNIC PRAHOVA SALINE, BY USING THE GEOPHYSICAL GROUND PENETRATING RADAR

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Abstract: *The study investigates the structural stability of the separating pillar between Mina Unirea and Mina Victoria and the galleries on Horizon XIV in the Cantacuzino Mine at Salina Slănic Prahova, Romania. Utilizing advanced ground-penetrating radar (GPR) techniques, the research identifies significant structural discontinuities, including anomalies and faults, that impact the integrity of underground salt mining operations. The geological and tectonic analysis highlights the complex formation processes and structural deformations influencing the area, with critical sections exhibiting thickness variations and fault orientations aligned with regional tectonic forces. Key findings emphasize the need for continuous monitoring, further geophysical investigations validation, and tailored consolidation measures to mitigate instability risks and ensure long-term operational safety. The conclusions provide essential insights for optimizing exploitation processes and guiding structural interventions to prevent potential collapses.*

Key words: *Ground-Penetrating Radar (GPR), Structural Stability, Structural Stability, Salina Slănic Prahova, Faults and Anomalies, Salt Deposit, Structural Monitoring, Consolidation Measures*

1. INTRODUCTION

Salina Slănic Prahova is one of the most important salt mining sites in Romania, with a long history of exploitation and significant geological potential. Due to tectonic activity and natural processes, the underground structure of the salt mine has experienced deformations that require constant monitoring to prevent risks associated with collapses or structural instabilities.

This study was conducted to assess the stability of the separating pillar between Mina Unirea and Mina Victoria and to analyze the cracks and fractures in the ceilings of the galleries on Horizon XIV of the Cantacuzino Mine. These investigations were carried out using advanced ground-penetrating radar (GPR) techniques to identify structural discontinuities and areas of instability (Geophysical GPR study of the Unirea Mine pillar and Horizon XIV galleries, Cantacuzino Mine, Salina Slănic Prahova).

Geology and Tectonogenesis of the Salt Deposit in Slănic Prahova

The salt deposit in Slănic Prahova is one of Romania's most significant salt reserves, with a complex geological origin. The formation of this deposit is closely

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linked to the tectonic evolution of the sedimentary basins in the Eastern Carpathians, where subsidence and salt accumulation occurred in evaporite environments.

Stratigraphy and Mineralogical Composition

The Slănic salt deposit belongs to the Miocene salt formation, specifically from the Upper Tortonian. The salt deposits were formed through the intense evaporation of lagoonal basins, leading to the precipitation of salt (NaCl) alongside other minerals such as calcium sulfates ($CaSO_4$), dolomite, and small amounts of marly clay [5]. The deposit primarily consists of layers of white, pure salt interspersed with dark gray salt layers containing clayey impurities (marls). These impurities, of terrigenous origin, reflect climatic and depositional environment variations.

The salt layer has considerable thickness and exhibits a relatively uniform structure in the mining area but with noticeable deformations in certain areas caused by tectonic processes.

Tectonogenesis and Structural Deformations

The salt deposits in the Slănic Prahova region have been affected by numerous tectonic episodes characterized by folds and faults that initially deformed the horizontal salt layers. Particularly during the Late Neogene period, the region underwent tectonic compression that led to the uplift and folding of sedimentary layers. These tectonic deformations resulted in major fold and fault structures, observable in the structural profile of the salt and highlighted by GPR investigations conducted at Salina Slănic (Geophysical GPR study of the Unirea Mine pillar and Horizon XIV galleries, Cantacuzino Mine, Salina Slănic Prahova).

The most common tectonic structures in this deposit are folds and reverse faults. Faults predominantly run in the east-west direction, aligned with the general orientation of the tectonic forces in the area. These structural discontinuities are observable both in Mina Unirea and Horizon XIV. For example, Fault 7, identified in the GPR study, reflects a major tectonic discontinuity with a variable depth of up to 43 meters, indicating significant tectonic movements in this area [5].

The fold and fault structures have influenced the overall stability of the deposit, with major instability risks in areas affected by these discontinuities. Folds observed in the pillars and galleries of the mine often have significant heights, reflecting the tectonic stresses acting on this massive salt body.

2. GEOPHYSICAL METHOD

2.1. Georadar method. Equipment Used

For this study, the Zond 12-3 Advanced GPR system was used, compliant with ASTM D6432-99 (2011) standards [1]. The system can record high-resolution data using a central frequency antenna of 300 MHz. The equipment features include:

- Time window: 1 - 2000 ns.
- Scanning rate: 320 scans/second.
- Measurements per second: 128/256/512/1024 x 16 bits.
- Selectable signal optimization filters: Weak, Strong, Super Strong.

Additionally, the Leica FlexLine TS07 total station was used for topographic measurements, enabling precise positioning of GPR profiles in the Stereo 70 coordinate system. The total station was essential for georeferencing the GPR profiles and measuring distances and angles (Geophysical GPR study of the Unirea Mine pillar and Horizon XIV galleries, Cantacuzino Mine, Salina Slănic Prahova).

2.2. Measurement Procedure

GPR measurements were conducted between September 1 and 6, 2024. For the pillar in Mina Unirea, data acquisition was performed vertically, using a team of industrial climbers who descended via rappelling to 3 meters above the mine's base level (Figures 1 and 2). In the case of Horizon XIV, measurements were taken on the ceilings of the galleries using a 300 MHz antenna mounted on a motorized platform (Figure 3) to ensure maximum proximity to the gallery ceilings (Geophysical GPR study of the Unirea Mine pillar and Horizon XIV galleries, Cantacuzino Mine, Salina Slănic Prahova).

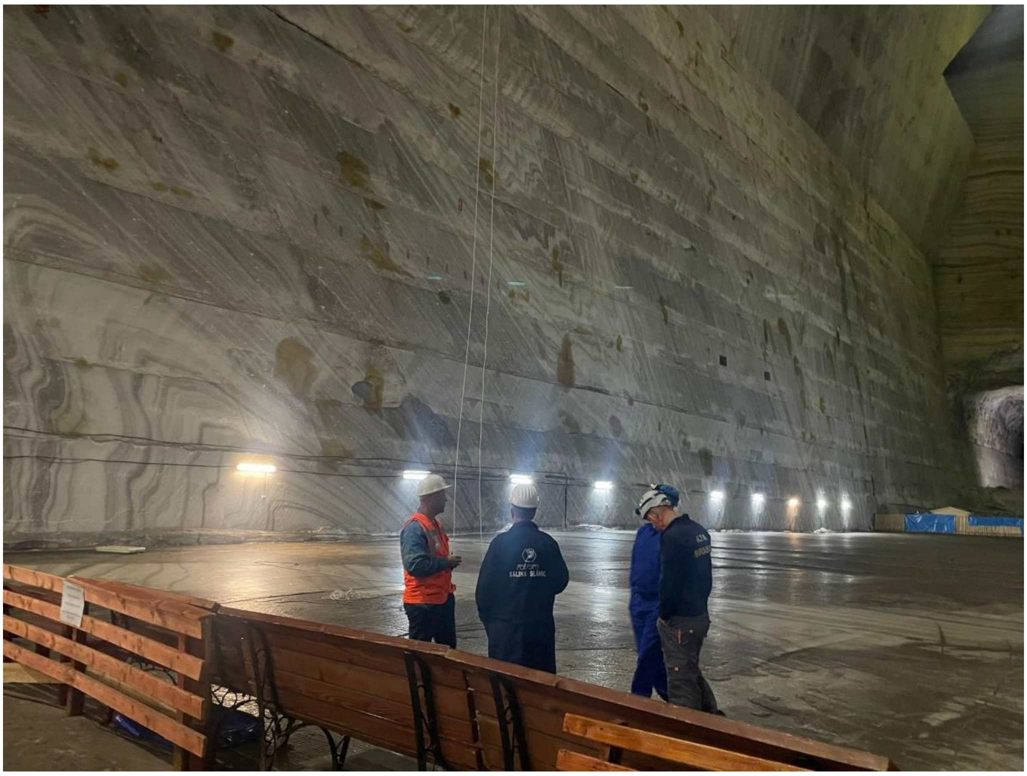

Figure 1. Image of the massive pillar between the Unirea and Victoria mines

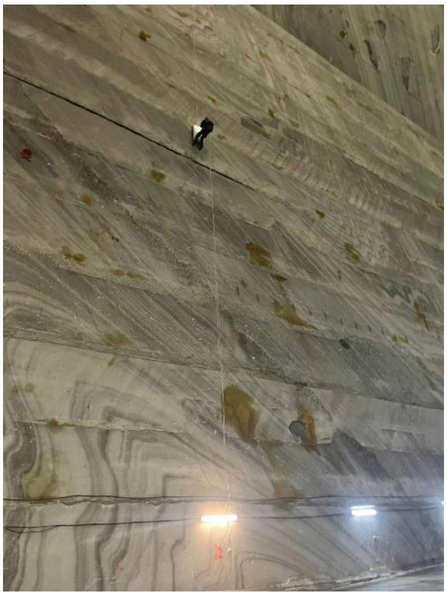

Figure 2. Acquisition of GPR measurements with the antenna attached during rappelling

Figure 3. GPR measurements with the antenna mounted on the motorized platform

Data was continuously acquired along profiles 30 meters in length and subsequently processed using Geolitix software to generate longitudinal and transverse sections. These sections were used to evaluate the pillar's thickness, the structural integrity of the ceilings, and potential instability risks [2].

2.3. Applied Standards

The geophysical measurements adhered to international standards ASTM D6429-99 and ASTM D6432-99, which provide guidelines for selecting and using geophysical methods for subsurface investigations [1]. Applying these standards ensures the accuracy and reproducibility of results, enabling the identification of structural discontinuities and risk areas.

3. RESULTS

3.1. Unirea Mine Pillar

Mina Victoria, located north of Mina Unirea, is separated from it by a massive pillar between 35-50 meters thickness. Previously, Mina Victoria was flooded with meteoric water, which could have caused dissolutions in the salt massif or affected the strength of mining works. The purpose of the GPR measurements was to identify any discontinuities within the separating pillar.

The equipment was set to measure with 1024 pulses/trace, using a measurement window of 1047 ns and a dielectric constant of 6. The salt massif where measurements were conducted is dry, with a clay content of less than 2-3%, allowing for excellent radar wave transmission through this rock.

To identify discontinuities in the pillar, 22 vertical GPR profiles were measured, with data acquisition performed from top to bottom (placement plan in Fig. 4). Profiles were measured by descending, using a GPR antenna applied directly to the pillar wall.

The GPR measurement results were georeferenced, processed, and interpreted, leading to the creation of a map showing variations in the pillar's thickness. Following the interpretation, a detailed map of these variations was obtained, based on which several longitudinal and transverse sections were generated.

The GPR results for the pillar separating Mina Unirea from Mina Victoria revealed significant variations in its thickness, potentially influencing medium- and long-term structural stability. Longitudinal sections A-A' and B-B' (detailed in Fig. 5) were crucial in determining these variations:

Longitudinal section A-A': The pillar thickness varies between 35 and 50 meters, with a gradual increase from 35 meters to 50 meters over a distance of 190 meters. This variation indicates a significant accumulation of material in certain areas, suggesting a relatively stable structure in most studied portions.

Longitudinal section B-B': Thickness varies between 40 and 50 meters, with a distribution similar to that observed in section A-A'. In both sections, areas with material accumulations indicate medium-term structural stability (Geophysical GPR study of the Unirea Mine pillar and Horizon XIV galleries, Cantacuzino Mine, Salina Slănic Prahova).

The transverse sections confirmed the thickness variations of the pillar (detailed in Fig. 6):

Section E-E': Thickness variation of 10 meters, suggesting potential structural instability risks in the 20-meter zone of the profile.

Other sections, such as G-G', showed minimal variations, indicating relative stability of the pillar in these areas (Geophysical GPR study of the Unirea Mine pillar and Horizon XIV galleries, Cantacuzino Mine, Salina Slănic Prahova).

The zone with abrupt thickness variations highlighted in transverse section E-E' shows significant thickness changes above the base of Mina Victoria. This suggests a zone affected by dissolutions or collapses of the pillar.

3.2. Horizon XIV

Horizon XIV of the salt exploitation was opened relatively recently. It is currently located beneath Mina Unirea, with a floor thickness of approximately 40 meters separating them. Following previous prospecting works, structural discontinuities and faults intersecting the gallery routes of Horizon XIV from Mina Unirea were identified. Thus, the planned GPR measurements were conducted on the ceilings of existing galleries using a motorized platform. The 300 MHz GPR antenna used was fixed on the platform at a distance of approximately 0.50 meters from the gallery ceilings, and measurements were conducted continuously at an advancement speed of 2-3 km/h. The equipment was set to measure with 1024 pulses/trace, using a measurement window of 1045 ns and a dielectric constant of 6. The salt massif where measurements were conducted is dry, with a clay content of less than 2-3%, allowing for excellent radar wave transmission through this rock.

The GPR measurements conducted on the ceilings of the galleries at Horizon XIV identified structural discontinuities. These discontinuities represent potential long-term instability risks, particularly in active exploitation front areas.

Among the most important anomalies and faults identified were:

Anomaly 1 (**Fig. 7**):

Orientation: East – West

Intersection zone: The anomaly's apex is located in the O7 – O8 pillars area.

Maximum depth: Traced to a depth of 42-43 meters.

Observations: Anomaly 1 is one of the major structural discontinuities in Horizon XIV, oriented east-west, potentially affecting the stability of pillars and the gallery ceiling structure in this area. Long-term risks associated with this anomaly include potential crack propagation towards Mina Victoria.

Anomaly 2 (**Fig. 8**):

Orientation: East – West

Intersection zone: The anomaly's apex is in the K8 – M8 pillars area.

Maximum depth: The anomaly was traced to a depth of 37-38 meters.

Observations: This anomaly shows a moderate-depth discontinuity. Its east-west orientation is similar to Anomaly 1, and its potential for structural instability must be monitored over time, given its proximity to Mina Victoria and other important underground structures.

Anomaly 3:

Orientation: East – West

Intersection zone: The anomaly's apex is in the K8 – M7 pillars area.

Maximum depth: Traced to a depth of 39-40 meters.

Observations: Anomaly 3 is one of the most significant discontinuities in Horizon XIV, with considerable depth. Over time, it could generate cracks in the gallery and pillar structures of Mina Victoria, amplifying instability risks.

Fault 4 (**Fig. 9**):

Orientation: North – South

Intersection zone: The fault's apex is in the K10 – K11 pillars area.

Maximum depth: Traced to a depth of 36-37 meters.

Observations: Unlike the other faults, Fault 4 has a north-south orientation, making it distinct in the overall structure. This fault could influence crack propagation in other directions over time, requiring special attention for potential consolidation works.

Fault 7 (**Fig. 10**):

Orientation: East – West

Intersection zone: The fault's apex is located in the I8 – I9 pillars area.

Maximum depth: Traced to a depth between 35 and 43 meters.

Observations: Fault 7 exhibits significant depth variation (35 to 43 meters), indicating a complex and potentially unstable structure in certain points. Over time, this fault could influence the structural integrity of the galleries and ceilings, necessitating careful monitoring.

Anomaly 8:

Orientation: East – West

Intersection Zone: The apex of the anomaly is located in the I8 – K10 pillars area.

Maximum Depth: The anomaly was tracked to a depth of 35-36 meters.

Observations: This is a relatively shallow anomaly compared to others, but it can still affect the underground structures in the I8 – K10 pillar area over time. The small depth variation suggests a more uniform discontinuity, but with a localized potential risk of instability.

Fault 10:

Orientation: East – West

Intersection Zone: The apex of the fault is located in the K12 – J12 pillars area.

Maximum Depth: The fault was tracked to a depth of 31-32 meters.

Observations: Fault 10 has a relatively shallow depth, which may indicate lower risks compared to others. However, its proximity to important pillars in Mina Victoria suggests it should be closely monitored, as even a small discontinuity can cause cracks in structures.

Anomaly 29:

Orientation: South – North

Intersection Zone: The apex of the anomaly is located in the L5 – J8 pillars area.

Maximum Depth: The anomaly was tracked to a depth of 33-40 meters.

Observations: Anomaly 29 is one of the deepest anomalies in Horizon XIV, oriented south-north. Over time, it presents significant structural instability risks in the L5 – J8 pillar area, where the depth variation is considerable.

All structural anomalies identified in Horizon XIV present potential structural risks, being located in critical areas that could affect the stability of the galleries and pillars in Mina Victoria over time. The varying orientation and depth of these anomalies indicate a complex geological structure with discontinuities that could lead to crack propagation, generating instabilities over time, particularly after the exploitation of Horizon XIV.

4. DISCUSSIONS

The interpretation of the ground-penetrating radar data highlighted several critical aspects regarding the stability of the underground structure at Salina Slănic Prahova. In both studied areas—the pillar between Mina Unirea and Mina Victoria, as well as the galleries of Horizon XIV in the Cantacuzino Mine—structural discontinuities were identified that require long-term monitoring and interventions [3].

The Pillar of Mina Unirea

The thickness variations identified in the longitudinal and transverse sections of the pillar suggest a structure that is largely stable; however, critical points exist. Section E-E' showed a thickness variation of up to 10 meters, indicating a potential instability zone. These variations may be caused by material accumulations in certain areas or by tectonic factors that have led to the compaction or dilation of the salt [4].

The risk of structural instability in the Mina Unirea pillar is significantly higher in areas with large thickness variations, where internal stresses can lead to collapses or cracking under extreme conditions. It is essential that these zones be periodically monitored, and, in the event of further degradation, consolidation measures should be implemented (Geophysical GPR study of the Unirea Mine pillar and Horizon XIV galleries, Cantacuzino Mine, Salina Slănic Prahova).

Horizon XIV

The results obtained for Horizon XIV revealed several anomalies and faults, many of which have east-west orientations, reflecting the primary direction of the tectonic forces that have impacted the area [5]. The identified anomalies, such as Anomaly 1 and Fault 7, represent major structural discontinuities that can affect the stability of the galleries. The primary risk is the propagation of cracks, which can lead to localized collapses in active exploitation areas (Geophysical GPR study of the Unirea Mine pillar and Horizon XIV galleries, Cantacuzino Mine, Salina Slănic Prahova).

Implications for the Future

Continuous monitoring of these structures is essential for assessing long-term instability risks. The use of additional geophysical investigation methods, such as seismic tomography, is recommended to validate the obtained results and to better evaluate the behavior of the salt structure at depth [2]. Additionally, further salt exploitation should be carried out carefully to avoid overloading structures already affected by fractures and faults.

5. CONCLUSIONS

Stability of the Mina Unirea Pillar:

The ground-penetrating radar study revealed variations in the thickness of the pillar ranging from 35 to 50 meters, with most areas showing relatively good stability.

However, critical sections, such as E-E', suggest the presence of potentially unstable zones that require constant monitoring.

Thickness variations may be associated with both material accumulations and tectonic factors, indicating the need for further studies to determine the exact causes.

Structural Risks in Horizon XIV:

The GPR analysis identified major anomalies and faults, such as Fault 7 and Anomaly 1, which can affect gallery stability. These discontinuities, predominantly oriented east-west, align with the primary direction of tectonic forces in the area.

The propagation of cracks and discontinuities could significantly impact the safety of operations, necessitating the implementation of preventive measures and specific reinforcements in vulnerable areas.

The Need for Continuous Monitoring:

Long-term monitoring of the pillar and galleries in Horizon XIV is essential to prevent collapses and structural instabilities. This should be carried out using modern investigation methods, such as seismic tomography and 3D analysis of GPR data.

Additional studies should include periodic assessments of the evolution of discontinuities to identify critical zones in time and minimize risks.

The Importance of Implementing Consolidation Measures:

In areas with abrupt thickness variations and identified instability, such as section E-E', immediate consolidation measures are crucial to prevent the collapse of underground structures.

Consolidation technologies must be tailored to the structural characteristics of the salt deposit to ensure safe long-term exploitation.

Study Contributions:

This study provides a solid foundation for evaluating the structural risks associated with the pillar between Mina Unirea and Mina Victoria, as well as the galleries of Horizon XIV.

The data and conclusions obtained contribute to optimizing the exploitation process and reducing risks, being relevant both for specialists and decision-makers involved in managing mining operations.

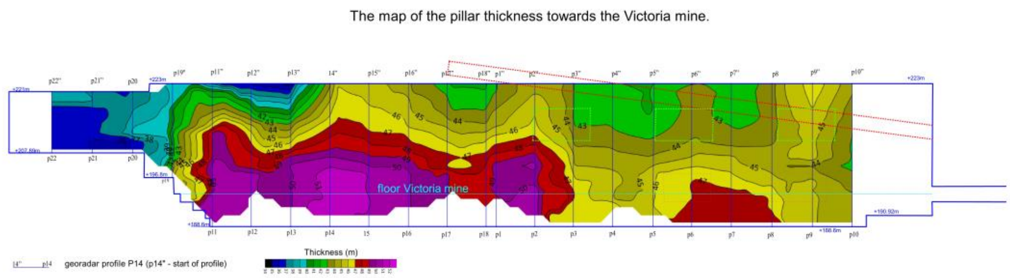

Figure 4. The map of the pillar thickness toward the Victoria mine

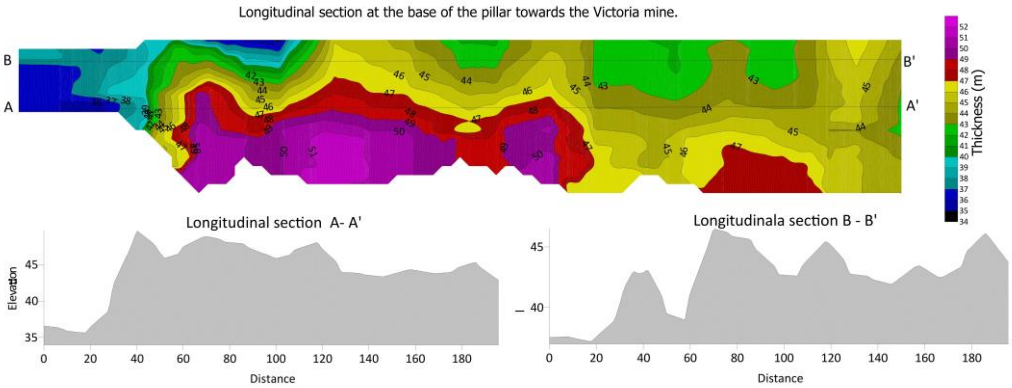

Figure 5. Longitudinal section at the base of the pillar towards the Victoria mine

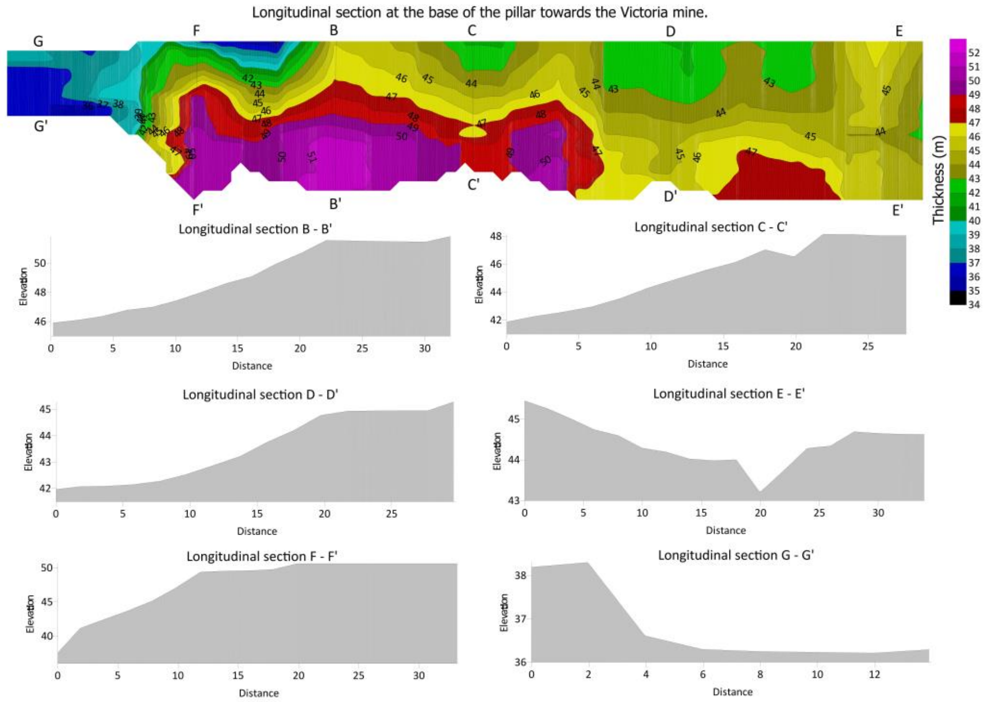

Figure 6. Longitudinal section at the base of the pillar towards the Victoria mine

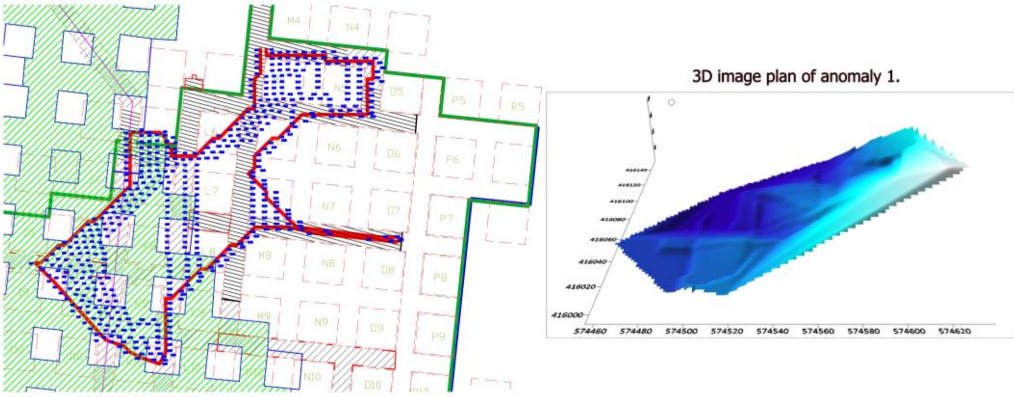

Figure 7. Annomaly 1 of the Horizont XIV

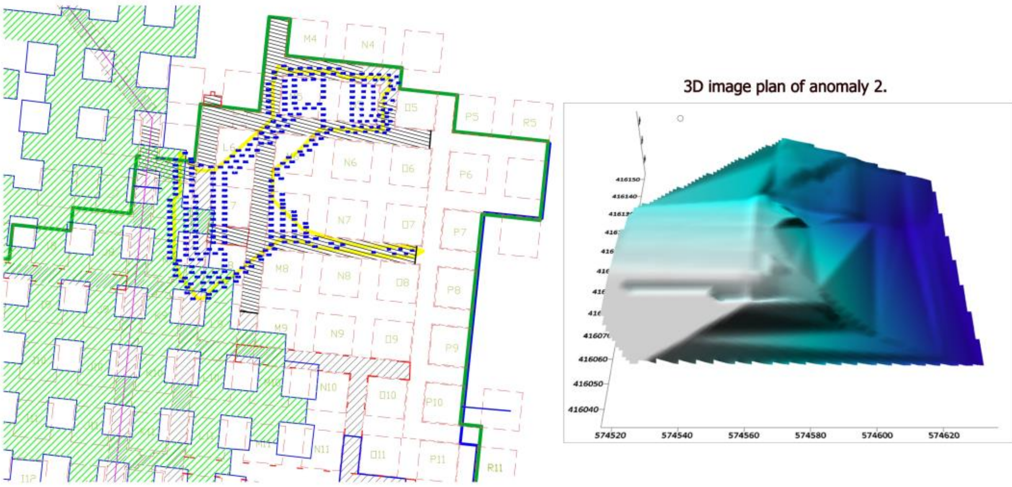

Figure 8. Annomaly 2 of the Horizont XIV

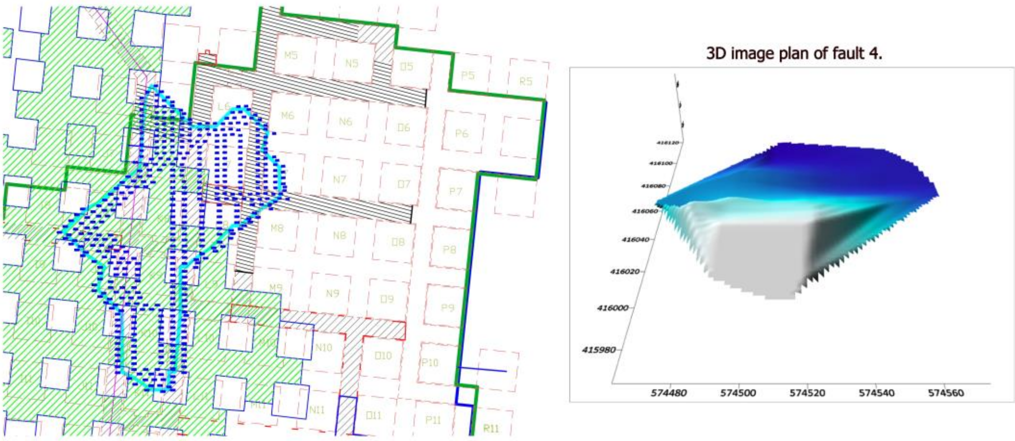

Figure 9. Fault 4 of the Horizont XIV

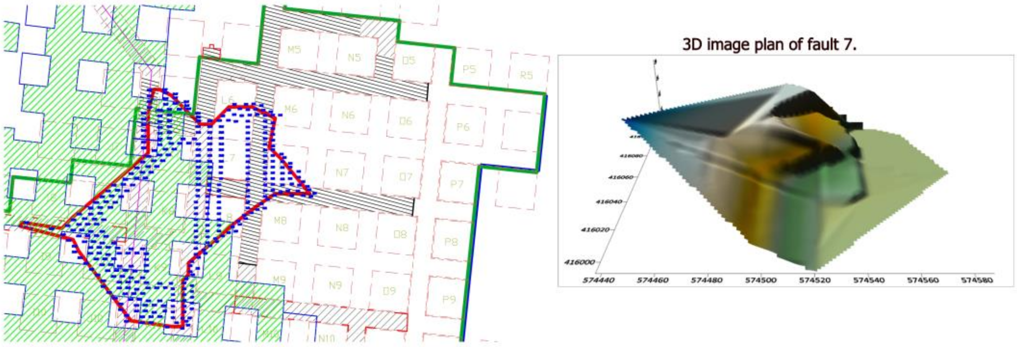

Figure 10. Fault 7 of the Horizont XIV

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STUDY OF CONSTRUCTIVE IMPROVEMENT AT THE CABLE WINDING DRUM OF THE LIFTING MECHANISM ON THE ESRC-1400 ROTOR EXCAVATOR

Bogdan-Zeno COZMA[1], Vlad Alexandru FLOREA[2]

Abstract: *Coal mining in quarries was used only at the beginning of the 20th century, it developed very quickly, with the improvement of excavators and appropriate transport systems. The boom lifting mechanism with the bucket wheel is placed on the counterweight box at the end of the balancing boom and allows the boom to be raised or lowered vertically, depending on the operating needs.*

Key words: *Advance mechanism, coal, CAD software*

1. INTRODUCTION

Coal mining in quarries was used only at the beginning of the 20th century, it developed very quickly, with the improvement of excavators and appropriate transport systems, so that in 1950 48% of the world's production of useful mineral substances was extracted from quarries, in 1970 this percentage increased to 75%. Currently, over 90% of the world's production of brown coal and lignite is extracted from quarries.

At the current stage, there is a transition from the extensive use of coal mining equipment to the intensive one, which leads to an increase in production not only through investments, but especially by increasing the utilization rates of installations and equipment.

At the global level, two types of lifting - lowering mechanisms of the arm of rotor excavators are currently used:

- hydraulic lifting - lowering mechanism with linear hydraulic power motors;
- lifting mechanism - lowering with mechanical winch, pulleys and cables.

The mechanism with winch, pulleys and metal cables is the most used.

Figure 1 shows an overview of the EsRc-1400 excavator in which the lifting mechanism and the related metal structure can be highlighted. [1]

The boom lifting mechanism with the bucket wheel is placed on the counterweight box at the end of the balancing boom and allows the boom to be raised or lowered vertically, depending on the operating needs.

The upper platform of the excavator is located above the base chassis and can rotate relative to it by means of the support and rotation bearing, Ø 8650 mm, with a toothed crown.

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Figure 1. Overview of the EsRc-1400 rotor excavator [3]

The toothed crown and the lower raceway of the bearing are solidly connected to the base chassis, and the upper raceway is solidly connected to the rotating platform. The rotation of the platform with the entire upper structure that rests on it is achieved using the rotation mechanism. The rotation mechanism is protected by the safety clutch that stops the operation in case of overload. In the middle of the platform is located the bearing of the connecting bridge between the excavator itself and the loading trolley.

The four pillars of the tower are supported on the rotating platform. The balancing arm is fixed to the tower, and on the opposite side of it, the bucket wheel arm is articulated by means of two axes.

The column that supports the block of cable guide rollers from the lifting mechanism of the bucket wheel arm is also articulated by the tower. At the end of the balancing arm is the tilting cabin for the ballast. The lifting mechanism of the arm is mounted on the ballast box. On the upper side (bracing) of the balancing arm, the track for the 10-ton crane is located, used for assembly and repairs. [4]

The end of the column articulated to the roller block is connected to the ballast box by means of two anchor cables. The rotating platform takes on compression loads from the superstructure, but also moments from its rotational movements.

2. CONSTRUCTION AND OPERATION OF THE LIFTING MECHANISM

Figure 2 shows the lifting mechanism, where the following are noted: 1 – electric motor 275 kW/1000 rpm; 2- elastic coupling 300 with brake disc Φ 710; 3 – brake 710/300 with shoes, counterweight and electrohydraulic lifter, 600 daN·m;

4 - cylindrical reducer 2H-M-1060-0; 5 – brake guard; 6 – half-coupling with brake disc; 7 - toothed coupling, maximum torque 72 000 N·m; 8- bearing Φ 200, var. I; 9 – pinion Z=19, m=22; 10 - bearing Φ 200, var. II; 11 – gear wheel Z=172, m=22; 12 – cable drum; 13 – chassis (ballast box construction); 14 – outer transmission guard.

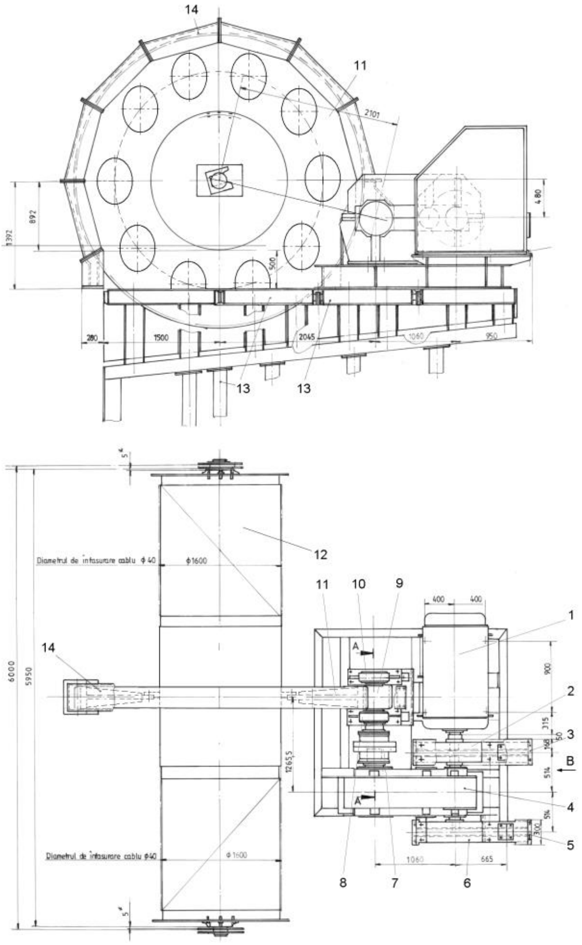

Figure 2. Excavator boom lifting-lowering mechanism [8]

The winch is driven by an electric motor that transmits movement to a reducer.

The reducer has two transmission stages, with cylindrical gears and bubble lubrication. The pinion shaft of the first stage protrudes from both ends. At one of the ends, the elastic coupling with the Ø710 brake washer is mounted, which connects to the electric motor, and at the other end, a brake washer with the same diameter Ø710 is mounted, and the two brakes with two shoes and counterweights are assembled on them.

Next, the movement from the reducer is transmitted through the gear coupling to the pinion shaft, which meshes with the cylindrical gear wheel, formed from two parts with a pitch diameter of 3784 mm. This wheel is connected by flanges to the metal construction of the drum, which is supported by a shaft on radial bushing bearings, with a cable laying diameter of 1600 mm.

Resting the bucket wheel on the ground is dangerous, due to the fact that the center of gravity of the entire excavator assembly is displaced. To ensure proper operation, safety devices are mounted on the boom lifting-lowering mechanism (centrifugal switch, rotation stroke limiter, hydraulic compression dynamometer).

The drum on which the traction cable is wound, figure 3, is a welded metal construction, on which the gear wheel and the cable ends are fixed, with assembly parts. In figure 3, the following notations have been made: 1 – drum shaft Φ 200; 2 – metal construction of the drum; 3 – gear wheel z=172, m=22; 4 – shaft locking plate; 5 – fixing plate; 6 – wear plate; 7 – bearing bush; 8 – cable clamp.

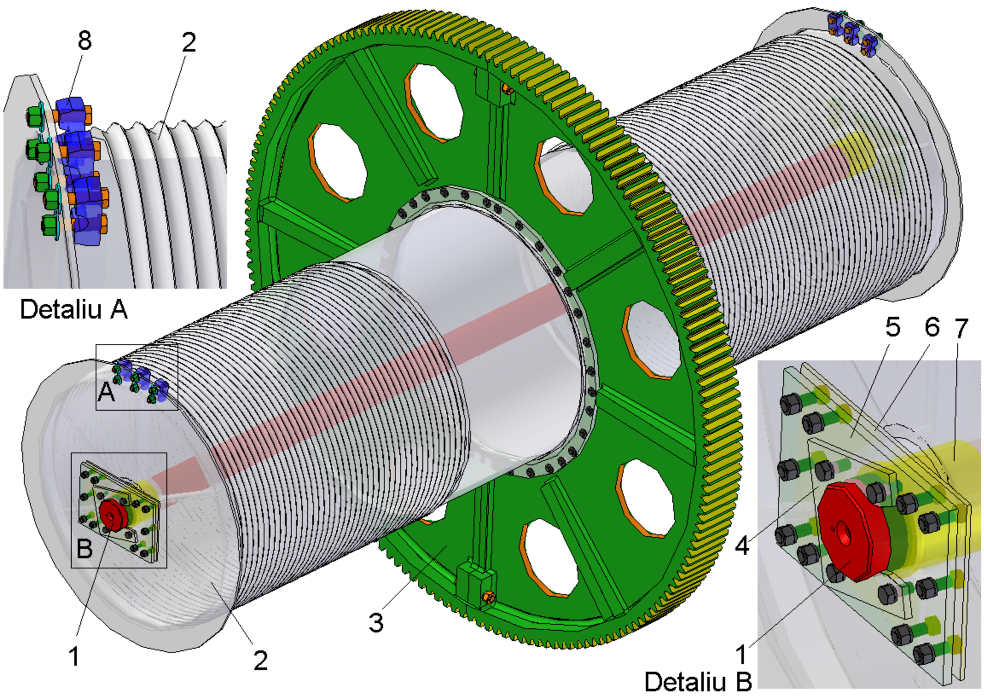

Figure 3. Cable reel [3]

The spatial representation in Figure 3 shows how the gear wheel is made of two pieces, with its mounting on the welded support on the metal construction of the drum, as well as how the cable ends are fixed to the metal construction and how the drum shaft is locked. [6]

3. CABLE REEL SIZING AND VERIFICATION

Figure 4 shows the calculation model of the cable winding drum of the excavator lifting mechanism, with the positioning of the cable forces in the horizontal plane F_{ch} and in the vertical plane F_{cv} and the forces in the cylindrical gear F_{ah} and F_{av}. For the cable forces, their variable position was taken on the range d_{38} = 144 ... 1816 mm with the pitch of the drum channel of 44 mm. The forces in the cylindrical gear were determined depending on the tangential force F_t and radial F_r of the gear, respectively, the positioning angle of the gear line with respect to the horizontal plane.

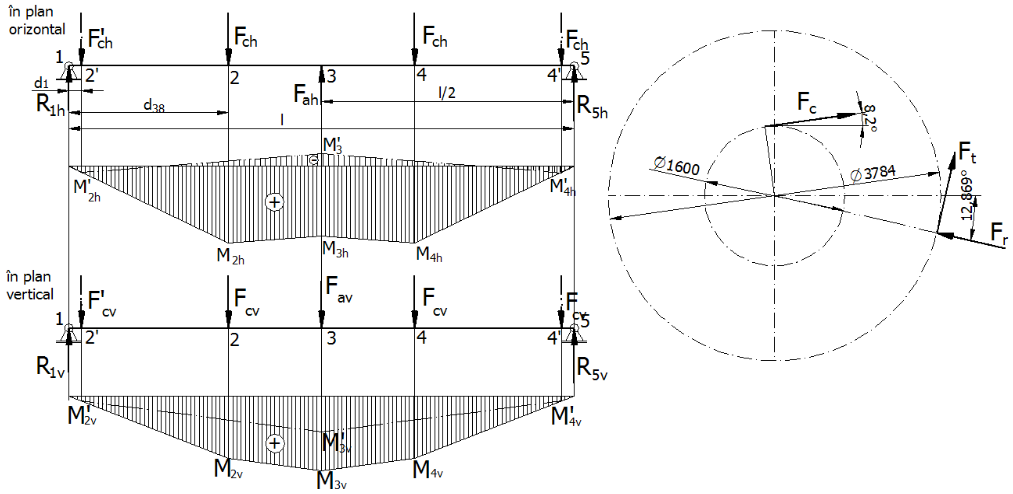

Figure 4. Calculation model of the cable reel [3]

Using the calculation model of the cable winding drum, the reactions in the drum bearings, the bending moments in the horizontal and vertical planes were determined and the equivalent stresses in the cable winding areas and in the central area of the drum were determined. The values of the bending stresses presented in figure 5 are lower than the allowable stress for alternating symmetrical loading of OT400 steel σ_a = 55 N/mm^2.

Also, the influence of axial and radial wear of the cable winding channels on their elongation was monitored, presented in figure 6 for 1 channel Δl_1, for 5 channels Δl_5 and for 10 channels Δl_{10}.

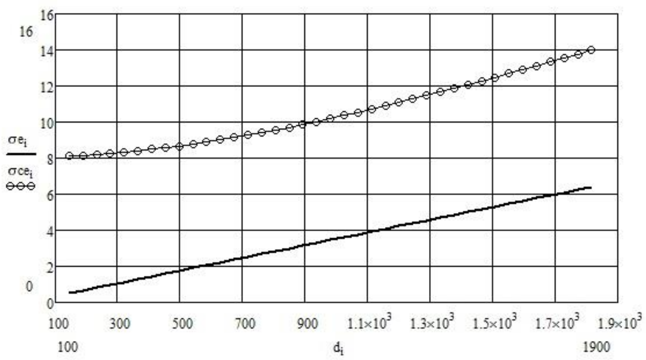

Figure 5. How bending stress varies depending on cable position [4]

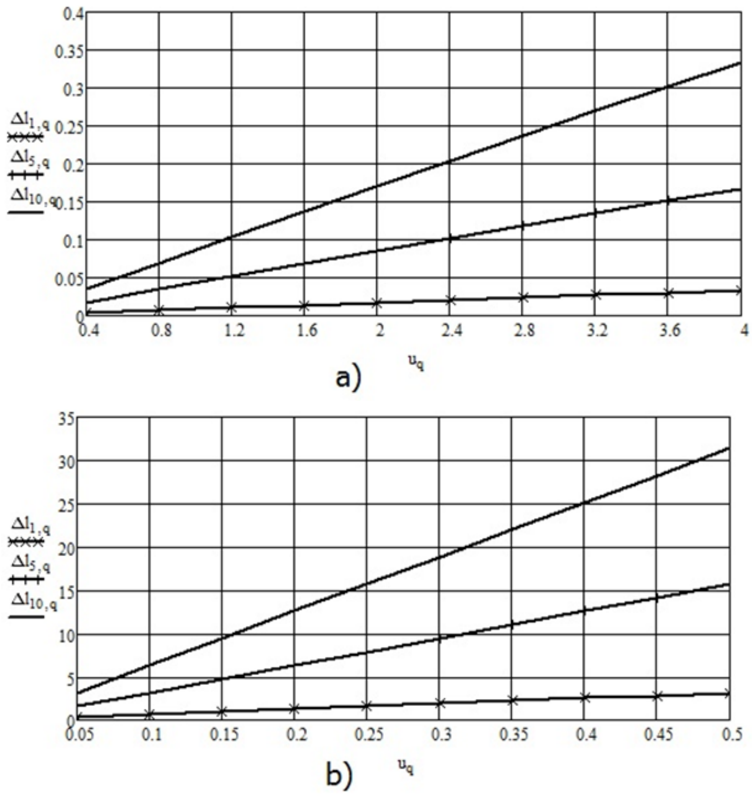

Figure 6. Influence of axial and radial wear of drum grooves on cable elongation

From figure 6 it can be seen that the cable elongation increases greatly with radial wear, having an influence approximately 100 times greater than axial wear.

4. SOLUTIONS TO IMPROVE THE CONSTRUCTION OF THE CABLE REEL

Starting from the defects that have appeared over time in the lifting-lowering mechanism of the excavator arm with a rotor, in conjunction with the experience gained in their exploitation, two constructive-functional variants of the drum for winding the traction cable were designed, which will be coded hereinafter as variant I and variant II.

Presentation of the drum for winding the cable – variant I

Figure 7 presents the overall solution of the drum for winding the traction cable, variant I, in the legend of which the component elements of this subassembly are mentioned, and from which, by comparison with the classic variant, presented in chapter I, the modernizations that have been carried out result. The new drum consists of: 1 – drum shaft Ø 200; 2 – metal construction of the drum; 3 – brake discs; 4 – gear wheel z=172, m=22; 5 – cable clamp; 6 – inspection cover; 7 – rubber gasket; 8 – fixing plate; 9 – shaft locking plate; 10 – wear plate; 11 – bearing bush.

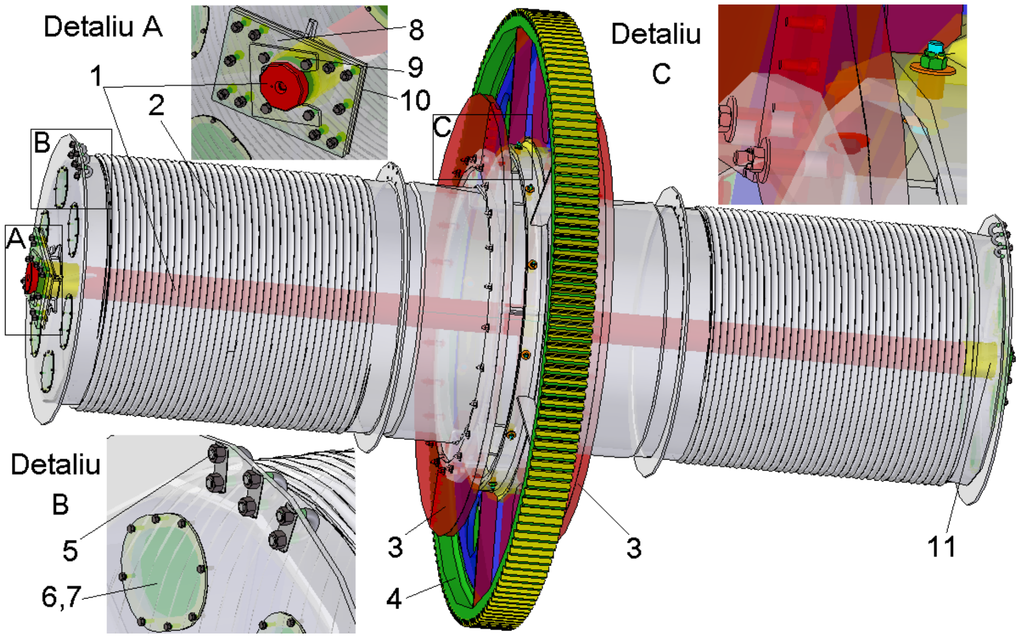

Figure 7. Overall solution of the cable winding drum – variant I. [8]

Thus, the following modifications can be highlighted, which at the same time constitute constructive improvements made to the lifting system as a whole:

1. On the metal construction of the drum, on either side of the gear wheel z=172, m=22, reference 4, two brake discs, reference 3, are fixed with screws, detail C, figure 7. These discs come into contact with the wear surface of the hydraulic brake calipers, resulting in direct braking of the drum, eliminating the stress on the cylindrical gear during braking.

2. On the metal construction of the drum, figure 7, two additional rings are provided, by welding, at the ends of the cable winding areas from the center of the drum, used to tie the cable end, detail B. Changing the cable connection from one side to the other is necessary because, in the area opposite the connection, where the cable is wound and unwound from the drum during the lifting-lowering process, a very pronounced wear of the cable guide channels occurs, due to the very high efforts in the cable. By changing the connections, the unused area becomes the active winding-unwinding area, which leads to doubling the drum's service life.

3. The gear wheel z=172, m=22, which is part of the external cylindrical gear, has been redesigned, being made in a welded construction, in one piece, with advantages regarding execution precision, assembly and operation conditions.

Presentation of the cable winding drum – variant II

Figure 8 shows the overall solution of the traction cable winding drum in variant II, a variant that is redesigned by 95%. [3]

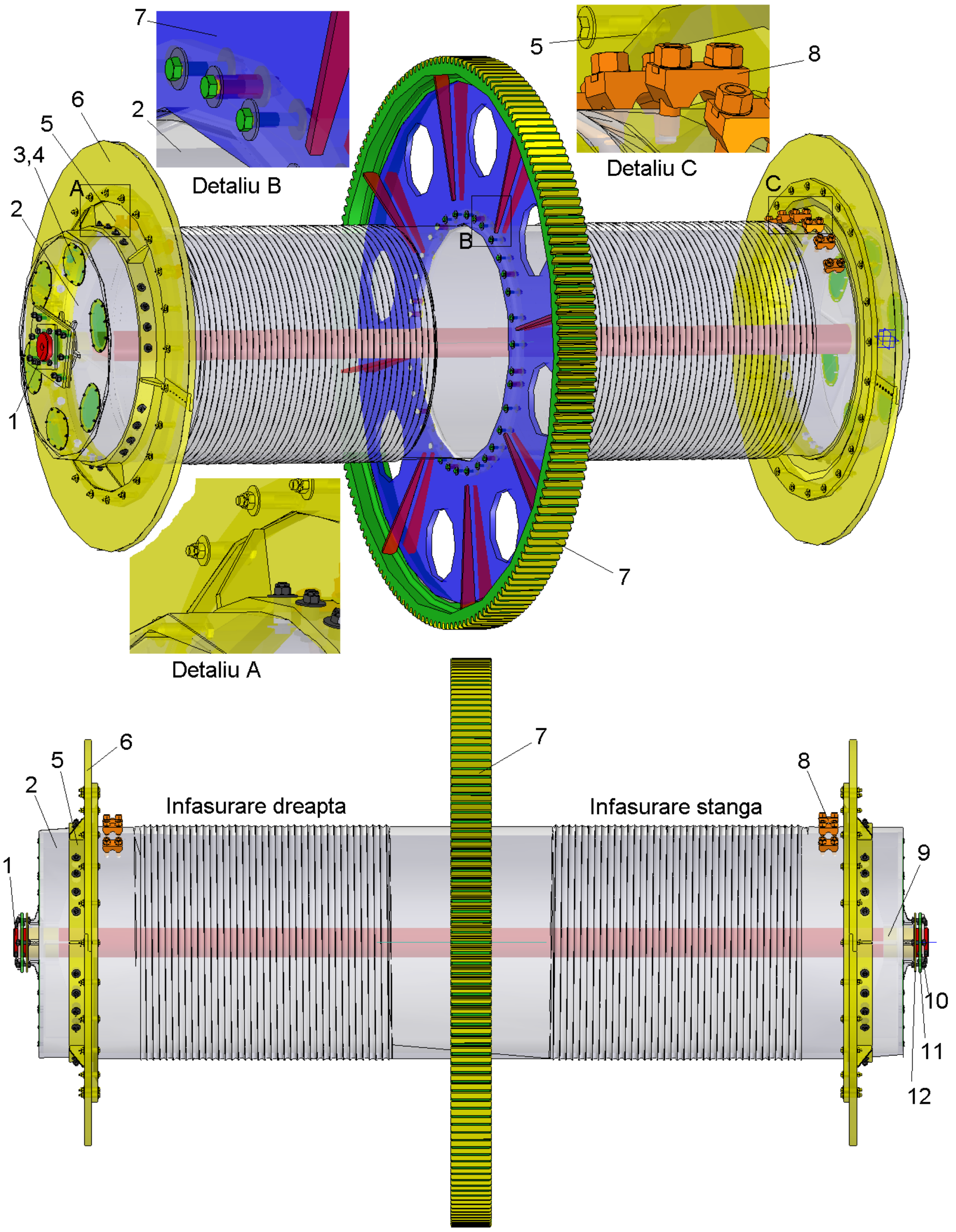

Figure 8. Overall solution of the brake drum with brake discs – variant II [8]

The meaning of the parts in figure 8 is as follows: 1 – drum shaft Ø 200; 2 - metal construction of the drum; 3 – inspection cover; 4 – rubber gasket; 5 – removable support for the brake disc; 6 – brake disc; 7 – gear wheel z=172, m=22; 8 – cable clamp; 9 - bearing bush; 10 – shaft locking plate; 11 – fixing plate; 12 – wear plate.

5. CONCLUSIONS

Two constructive variants of the cable winding drum are presented, in which the brake mechanism discs are mounted directly on the drum drum, after the external cylindrical gear.

The first variant involves mounting the brake discs, and therefore the brake mechanism, in the vicinity of the longitudinal center of the cable winding drum. The point where the traction cable is connected to the drum's strength structure is reconsidered, the cable fixing collar is redesigned in order to increase the operating safety of the mechanism, the cylindrical gear wheel as part of the open cylindrical mechanism is redesigned.

The second drum variant, designed to fit into the excavator's lifting-lowering mechanism assembly, is a new, simple concept, with constructive and functional advantages, in which the brake discs are arranged towards the ends of the drum. It has the great advantage that the wear elements are easily removable, which greatly simplifies maintenance activities.

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THE VALORIZATION OF WASTE DUMPS FROM THE JIU VALLEY IN THE CONTEXT OF THE CIRCULAR ECONOMY

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Abstract: *The sterile deposits resulting from extracting and processing the coal from Jiu Valley contain a proportion of over 5% fuel mass, which is the subject of the research regarding the possibilities of recovering and economical taking over. The non-combustible mineral constituents can be capitalized as basic materials in the construction materials industry or for some available minerals extraction. By processing waste dumps can be made and environmental rehabilitation works, which can be supported with funds from environmental protection. In order to prevent and reduce the pollution of the areas affected by these dirt-heaps, for the ecological change over and the rehabilitation of the affected areas from the coal field, an environmental management project has been made out.*

Key words: *coal waste dumps, technological flow, pollution, circular economy*

1. INTRODUCTION

The dirt-heaps resulted from coal mining have different structures. That is a consequence of green coal processing, storage of the filter-press cakes resulted from the filtration of the sterile sludge (existing into the waste waters) as well as of the ash from the power station plants. In order to prevent and reduce the pollution of the areas affected by these dirt-heaps, for the ecological change over and the rehabilitation of the affected areas from the coal field, an environmental management project has been conducted. The main deficiency of this project consists in the non-evaluation of the capitalization of secondary resources that exist in these deposits. The present paper represents an approach on this matter, making an option on the reduction of the mineral mass volume. This is the subject of ecological rehabilitation by supplying the energetic minerals and basic materials as construction resources, which exist in the present sterile deposits. [1], [11], [12].

2. EXPERIMENTAL RESEARCH

The reusable secondary resources represent the share of secondary resources that can be taken out and economical effectively reused, depending on the potential of the resources, the level of development of recovery technologies; the energy and reusable materials reference costs level, being time dynamic.

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The presence of an important fuel potential in the stored sterile mass justifies the research of the recovering possibilities and the energetic capitalization, together with the current production. Thus, in some of the sterile deposits the combustion value is over 1500 kcal/kg and they are constituted as secondary energetic resources resulting from the primary technological process of valuing the exhausted coal. [1],[2],[7].

Thus, at the present time, the tailings dumps accumulate a total volume of approximately 37 million m3, occupying around 250 ha of land.

The recovering activity of combustible material must be linked to the clay-bearing and siliceous minerals constituents used in construction materials production. The mineralogical composition of the material from the deposit, mixed with the sludge from the water treatment stations and other ingredients can reclaim the degraded soils.

The preliminary research of the physical-mechanical and processing characteristics of the deposits shows the energetic potential, highlighting a few parameters which are presented in the following graphic.

The content in macroelements of the sterile from the three studied dirt-heaps shows a high amount of SiO_2 and Al_2O_3 and relatively low amount of the other macroelements.

The research points out the possibility of producing fictile blocks, roof tiles and other construction materials. [4],[3].

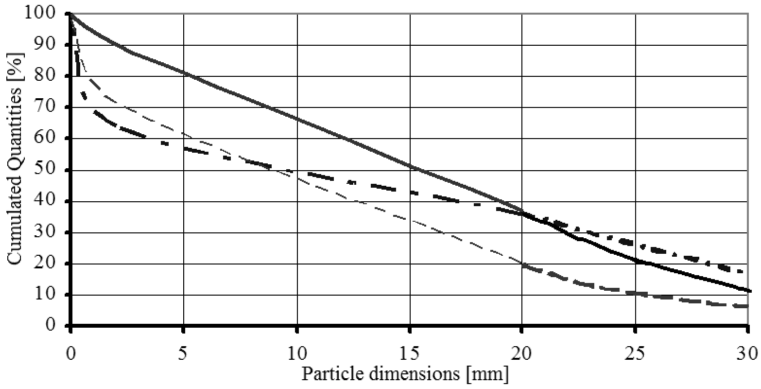

Figure 1. The grading composition of the sterile from the deposits

Table 1. The comparative mineralogical analysis between the carboniferous schist and the clays

Mineralogical constituents	Compositions, %		
	Carboniferous schist	**Yellow clay**	**Grey clay**
Argillaceous minerals	-	30 - 40	35 - 40
Quartz	5 - 10	20 - 40	20
Feldspates	5	10 - 15	10
Kaolinite	30	-	-
Calcite	5	-	-
Hydrobiotite	10	-	-
Muscovite	5	2 - 5	3

The sterile reprocessing involves extracting useful constituents, but remains a less explored field even if it can transform the mining sterile dirt-heaps from the Jiu Valley into Reusable Secondary Resources.

Table 2. The comparative chemical analysis between carboniferous schist and clays

Chemical constituents	**Compositions, %**		
	Carboniferous schist	**Yellow clay**	**Grey clay**
SiO_2	34.72 - 40.03	46.31 - 67.56	45.31 - 49.57
Al_2O_3	16.02 - 19.9	13.87 - 16.84	16.14 - 16.59
Fe_2O_3	2.62 - 3.97	4.53 - 7.31	6.38 - 6.74
TiO_2	0.37 - 0.67	0.00 - 0.89	0.00 - 0.93
CaO	1.40 - 2.8	1.95 - 11.69	7.68 - 10.93
MgO	0.90 - 1.55	1.35 - 2.60	2.47 - 2.88
Na_2O	0.23 - 1.65	0.90 - 1.38	1.03 - 1.22
K_2O	0.27 - 1.74	1.93 - 2.34	2.06 - 2.39
S	0.08 - 1.00	-	-
SO_3	0.00 - 1.74	0.00 - 0.09	0.00 - 0.09
P.C.	30.94 - 41.08	5.42 - 14.39	12.42 - 13.9

Table 3. The densimetric analysis on samples from the sterile stored in different areas

Densimetric class [kg/ dm^3]	**Petrila q_i [%]**	**Coroeşti q_i [%]**	**Lupeni q_i [%]**
- 1.48	6.67	2.79	8.19
1.48 – 1.65	3.20	1.15	2.58
1.65 – 1.75	1.67	1.32	2.19
1.75 – 1.9	5.31	2.29	3.02
+ 1.9	83.15	92.45	84.02

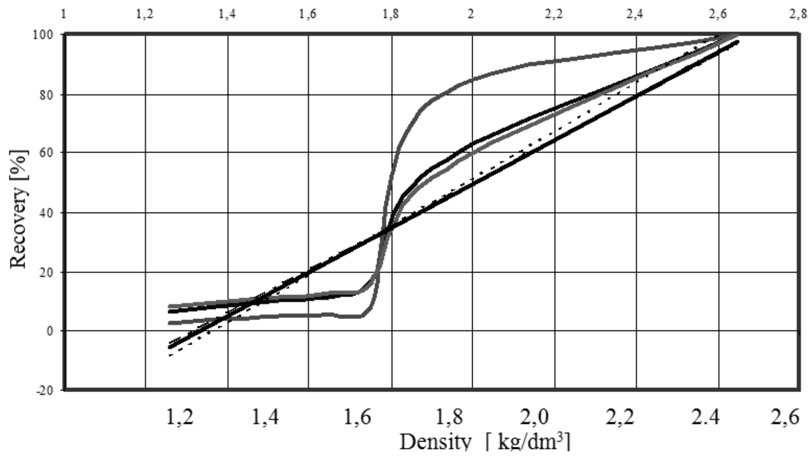

Figure 2. The variation of the combustible mass recovered from the dirt-heaps' sterile in the Jiu Valley

The combustible constituents recovered from the sterile dirt-heaps will require changes of the current earth-surveying configurations of the deposits becoming an opportunity to foresee ecological rehabilitation works.

It is estimated that the restoring of the final sterile will raise specific problems due to the greatest amount of clay-bearing minerals than can be found, nowadays, in the dirt-heaps.

The sterile material will be used at the construction area of the final sterile dirt-heap bank slope, and its disposal will be controlled, depending on the aggregates, in such way that the deposit stability to be ensured. The designing of the final deposit will take into account the exigencies required for ecological deposits.

2.1. Research concerning the possibility of capitalization the combustible mass from the E.M.Lupeni waste dumps

The recovery of combustible material must be related to the use, at least partially, new tailings from the process for the production of construction materials, possibly extraction of useful mineral components.

The capitalization of secondary energy resources present in the bulk deposits formed over time in each processing plant requires a detailed knowledge of the areas with higher content of fuel mass, to be subject to extraction and processing. [4], [5],[6].

In this work must be carried sampling and analysis of mineralogical and combustible components. Also take into consideration the possibility of access to machinery for the extraction and transport of the concentrate, as most dumps are located on rough roads and existing roads become impassable under a higher level of precipitation.

Final waste storage will raise specific issues due to high mineral content and clay material than are currently in the dumps. In addition there are much finer grains because wet processing will promote further degradation of the mineral material component. Purchase or local design and manufacture of mobile mining and processing plant tailings involves investments that are required to be identified sources of funding especially in the area of environmental rehabilitation facilities.

Based on a serious analysis of the dressability characteristics on granulometric classes processed routinely at Preparation Lupeni, have outlined the following two technological options that offer the possibility of increasing the recovery of clean coal products obtained.

1. Technological variant I, of coal waste processing on granulometric classes: 40-80; 0.5-40 and -0.5 mm;
2. Technological variant II of waste coal processing on granulometric classes:
0.5-40 and -0.5 mm.

Theoretical foundations of 0.5-40 mm size fraction possibility to be processed by jigging and characteristics of the material treated in these options are presented below. To determine the limits of particle size of the material which can be treated in the jigging machine Wedag Batac, based on density analysis of raw coal was passed to determine the maximum diameter of coal from feeding machine.

For this purpose is calculated simpthotic ranking coefficient. This coefficient for the N-R domain, according to Richards's theory is : [5]

$$q = \sqrt{e_{st}} \tag{1}$$

Where: e_{st} - coefficient of simpthoticity in fall conditions hampered;

$$e_{st} = \frac{\delta_2 - \rho_a}{\delta_1 - \rho_a} = \frac{d_1}{d_2} \tag{2}$$

Where: δ_1 - the density of easy product
- δ_2 – density of heavy product
- ρ_a – the bulk density of material bed in jigg compartment
- d_1 – the size of easy range
- d_2 – the size of heavy range

$$\rho_a = (1 - \varepsilon)\ \delta_m + \varepsilon\Delta = (1 – 0{,}37)\ .\ 1{,}744 + 037\ .\ 1 = 1{,}45\ kg/dm^3 \tag{3}$$

Where: ε - raising coefficient of material bed

- δ_m – average density of coal from the material bed

- Δ - water density

$$\delta_m = \frac{\sum v_i \cdot \delta_i}{\sum v_i} = \frac{39.2 \cdot 1960\ + 46.6 \cdot 1744}{85.4} = 1699\, kg / dm^3 \tag{4}$$

Where: v_i- quantities percent of densimetric classes with δ_i density

δ_0 – the bulk density, which for small coal is: 0,9 – 1,1 kg/dm^3.

The experimental trial on coal sample indicated a value of 1,16 kg/dm^3.

$$\varepsilon = 1\frac{\delta_0}{\delta_m} = 1\frac{1160}{1699} = 0.32 \tag{5}$$

$$\varepsilon_{st} = \frac{\delta_2 - \rho_a}{\delta_1 - \rho_a} = \frac{2.090\ - 1.5}{1.865\ - 1.5} = 1.61 \tag{6}$$

$$q = \sqrt{e_{st}} = \sqrt{1{,}61} = 1{,}26 \tag{7}$$

The simpthotic ranking coefficient is the ratio of two row limit velocities of particles fall

$$q = \frac{v_{01}}{v_{02}} \tag{8}$$

Where: v_{01}- limit velocity fall of the biggest particles from the easy product;

v_{02} – limit velocity fall of the smallest particle from the heavy product.

The limit velocity fall is calculated with the next relation:

$$v_{01} = k_{N-R} \cdot \theta \sqrt{\frac{\delta - \Delta}{\Delta}} \tag{9}$$

Where θ is impeding factor and K_{N-R} is Newton-Rittinger constantr

$$\theta = \frac{(\rho - \rho_A) \cdot \eta}{(\rho - \Delta) \cdot \eta_{st}} = 0.24 \tag{10}$$

Where η_{st} is viscosity in impeding conditions

$$\eta_{st} = (1 +2,5 \,.\, c +7,35\, c^2 + 16,2 \,.\, c^3) = 1,33 \,.10^{-3}\, Ns/m^2 \tag{11}$$

$$v_{01} = k_{N-R} \cdot \theta \sqrt{d_2 \frac{\delta_2 - \Delta}{\Delta}} = 2.73 \cdot 0.24 \sqrt{0.5 \cdot 10^{-3} \frac{2090 - 1000}{1000}} = 0.015\, m/s \tag{12}$$

$$v_{01} = v_{02} \,.\, q = 0,015 \,.\, 1,26 = 0,019 \text{ m/s} \tag{13}$$

Explaining $v_{01,}$ we get off the size of the biggest easy particle, d_1.

$$d_1 = \frac{{v_{01}}^2 \cdot \Delta}{\theta^2 \cdot {k_{N-R}}^2 \cdot (\delta_1 - \Delta)} = 0.040\, m \tag{14}$$

It follows from the above results that the limit dimensions of the material to be processed by jigging, are 0.5 and 40 mm. To achieve class 0,5 - 40 mm raw material should be placed on a screen mesh size θ = 48 mm, and must be made before jigging a slurry removal on a curved screen with holes spaced at θ = 1 mm.

Taking into account that the beneficiary is required technological concentrate 0-40mm, we find that jigging machine can process material in class size from 0.5 to 40 mm, maximum size being smaller than the size limit that can be used to jigging process. Therefore, in the following we calculate the circuit breaker to reduce the size of the coal supplied below 40mm.

Crushing scheme that is appropriate is an open circuit breaker with elimination + 40 mm from the crusher feeding. Given the standard of ranking areas and that the crossing get a small amount of pellets difficult for classification was adopted for the area classifying θ = 48mm yields ranking with an efficiency η = 80 %.[12].

The figure 3 presents a technological variant of recovery wastes dumps from E.M.Lupeni.

3. CONCLUSIONS

The presence of an important fuel potential in the stored sterile mass justifies the research of the recovering possibilities and the energetic capitalization, together with the current production.

The capitalization of the secondary resources existing in the mass of the deposits molded in time at each processing plant requires detailed knowledge of the areas with higher contents of combustible mass that can make the subject of extracting and processing.

The densimetric class analysis of the aggregates and the ash content of the sterile, show that there are no categories or fractions that can be selectively taken out from the mining mass.

The densimetric analysis of the sterile from under 20mm class, for the dirt-heaps from Petrila, Coroesti and Lupeni processing plants shows that the density range in between 1.75 – 1.85 kg/dm^3.

The shape of the processing curves and the calculation of the variation statistical index of the gravitational concentration of the material from Petrila dirt-heap, points out a very difficult processing behavior.

The capitalization of secondary energy resources present in the bulk deposits formed over time in each processing plant requires a detailed knowledge of the areas with higher content of fuel mass, to be subject to extraction and processing.

The most rapidly adopted and predictable costs lowest consists of building at angular station a installation of ranking – manual assortment coal and crushing at 40 mm. The final waste (+ 40 mm) can be used to a base dam from processing tailings deposit - class - 40 mm. Concentration can be made in Rheo dense medium separator. The water needed to be taken from reservoirs upstream of the discharge branches.

Final waste storage will raise specific issues due to high mineral content and clay material than are currently in the dumps. In addition there are much finer grains because wet processing will promote further degradation of the mineral material component. Purchase or local design and manufacture of mobile mining and processing plant tailings involves investments that are required to be identified sources of funding especially in the area of environmental rehabilitation facilities.

The recovery of combustible material must be related to the use, at least partially, new tailings from the process for the production of construction materials, possibly extraction of useful mineral components.

Estimated earnings, at this stage of research, we can consider acceptable for an investment in the area and also by processing tailings can be made and work environmental rehabilitation, which can be supported with environmental protection fund. The conclusions of the current study can form the basis for a project operating branch dump no. II Lupeni and successful experiment to exploit the mass body dump may be a reason for the extension and improvement of technology at other coal dumps in the Jiu Valley.

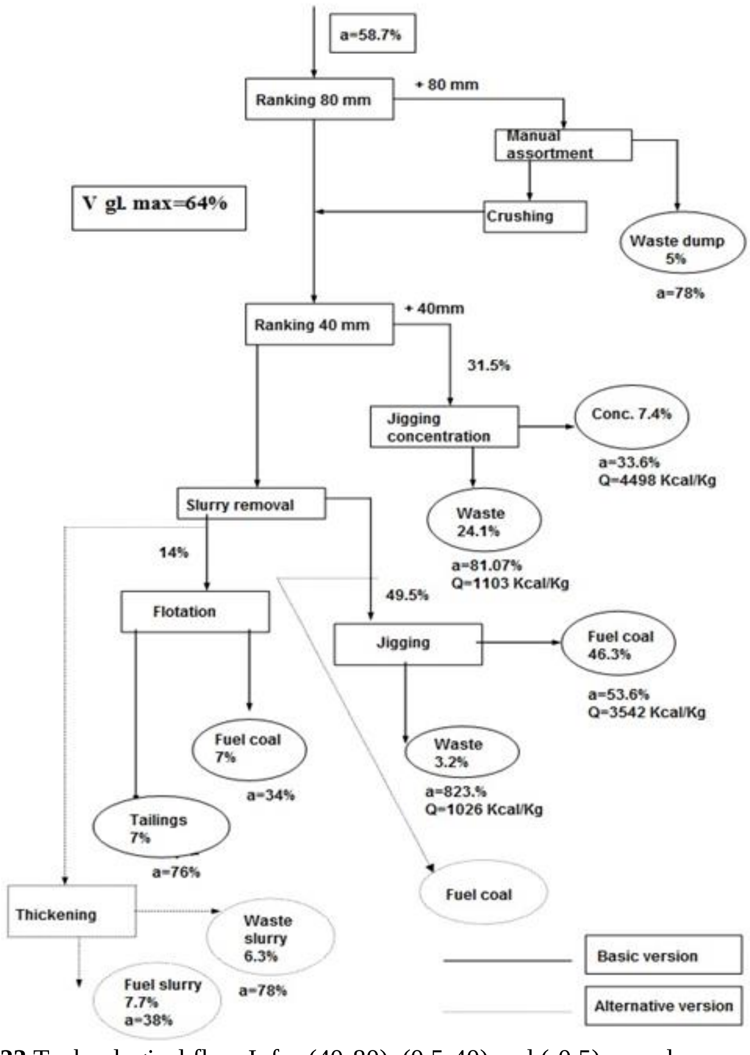

Figure 23 Technological flow I, for (40-80), (0.5-40) and (-0.5) mm classes processing

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TECHNOLOGICAL CONCEPTS REGARDING THE EXTRACTION OF HEAVY METALS FROM MINE WATERS

Camelia BĂDULESCU [1]

Abstract: *Mining activity has produced multiple and varied negative effects on the environment, specific to this industry. In particular, it generated the existence of numerous sources of mine water at the national level, which represents a vast and difficult problem to solve, technically and financially. There are few technological alternatives for mine water treatment, depending on the type of pollutant [16]: treatment for heavy metal removal only, insufficient from a legislative and ecological impact. This alternative can be implemented with relatively simple technologies and acceptable costs. Alongside with the removal of heavy metals, the content of sulfate ion (anion specific to mine waters), as well as of calcium and magnesium ions (species existing in the mine water and introduced to treatment) is reduced.*

Key words: *acidic waters, quality of mine waters, technological concepts*

1. INTRODUCTION

The effects of the acidic waters on the environment have become more visible over the years, a lot of research being focused on the development of remedial techniques, respectively control of the source of generation of acidic waters and their migration route [18]. Source control methods are focused on controlling the generation of acid waters at the site of their formation.

The restructuring of the mining sector in Romania involved the stoppage of activity for several hundred mines. Currently it is of very important to implement environmental protection measures for closure/post-closure, quality monitoring of evacuations, technical solutions for depollution of waters impure with heavy metals and other pollutants.

An adequate framework for the promotion of environmental management at the European level is required by Romania's accession to the EU, as it is necessary to fulfill all commitments undertaken in the field of environmental protection related to mining activity.[19], [20].

National statistics and observations indicate water and soil pollution as one of the most visible effects of mining activities. Around mining operations, tailings dumps, settling ponds and ore processing plants, surface and underground water are polluted with heavy metals (Pb, Cu, Zn, Cd, Cr, etc.), dangerous species for the aquatic biocenosis or for humans and with bioaccumulation potential. The main vector of heavy metal

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pollution is mine waters with a variable pH, generally acidic and with a high content of salts.

In Romania, starting with the year 1989, a process of drafting and amending the legislation in the field of the environment, including the one related to water, began. Thus, in 1996, a new water law no. 107, which is later amended and supplemented by law 310/2004. STAS no. 4706 of 1988 regarding the quality categories of surface water is replaced by Order 1146/2002 for the approval of the Normative on the reference objectives for the classification of surface water quality which, replaced by Order no. 161/2006 of the Minister of Environment and Water Management for the approval of the Normative regarding the classification of surface water quality in order to establish the ecological status of water bodies.

Regarding the quality of mine waters from non-ferrous metal mining, a great variability of the impurity matrix from one source to another and a variability over time for the same source was found. For the alkaline-earth metals, the following areas of variation were found:

Ca: 22 – 444 mg/l

Mg: 9 -1321 mg/l

Sulfate: 22- 10700 mg/l

Chloride: < 300 mg/l (in general < 30 mg/l; 80-300 mg/l for Turt Ghezuri, Penigher, Socea and Baia Sprie Tunel)

As a rule, low pH and high load in heavy metals mean high concentrations of sulfate and, in general, Ca^{2+} and Mg^{2+}.

2. TECHNOLOGICAL CONCEPTS

2.1. Technological concepts implemented at existing mine water treatment stations in the country

The technologies applied industrially in Romania for the purification of mine waters are the following:

a) Lime precipitation technology - global precipitation of metals in one step - applied, for example, to the Boița Hațeg mine water treatment plant, Borșa Emerik, Mestecăniș, Turț, Țibleș, Socea.

The characteristic note of this type of treatment plants is the provision of a single step of pH/oxidation/metal precipitation correction, thus not being possible to operate in steps.

b) Lime precipitation technology - metal precipitation in three reaction steps - Herja mine water treatment plant.

This technology has a higher complexity and proposes the removal of heavy metals at different pH values by oxidation/precipitation, with the recovery of hydroxide sludges with variable compositions. [2],[4].

<u>Step 1</u>: oxidation FeII → FeIII with air, precipitation FeII and FeIII as $Fe(OH)_3$ at pH = 5

$2Fe(OH)_2 + 1/2O_2 + H_2O \longrightarrow 2Fe(OH)_3$

$Fe_2(SO_4)_3 + 3\,Ca(OH)_2 \longrightarrow 2Fe(OH)_3 + 3CaSO_4$

$FeSO_4 + Ca(OH)_2 \longrightarrow Fe(OH)_2 + CaSO_4$

Step 2: precipitation Zn at pH = 7,5 and recovery slury of $Zn(OH)_2$

$ZnSO_4 + Ca(OH)_2 \longrightarrow Zn(OH)_2 + CaSO_4$

The alluminium concentration is arround 433mg/l, so its precipitation must also be taken into account.

$Al_2 (SO_4)_3 + 3 Ca(OH)_2 \longrightarrow 2Al(OH)_3 + 3CaSO_4$

Step 3: precipitation MnII and recovery slurry of $Mn(OH)_2$ la pH = 8,5

$MnSO_4 + Ca(OH)_2 \longrightarrow Mn(OH)_2 + CaSO_4$

This technology is interesting because it allows the relatively selective precipitation of useful elements, but it has the following weak points:

Step 1:

- the oxidation process of Fe II to Fe III at pH ≈ 5 has a low speed (becomes significant at pH > 6.5, optimum pH ≈ 8). It is known that pH > 8.5 is needed for the precipitation of Fe II.
- the removal of iron in the first step leads to poor results in the removal of manganese in the third step
- for the advanced removal of manganese, an oxidation / precipitation process is often necessary at pH > 8.5 (necessary to introduce air in the 3rd stage).

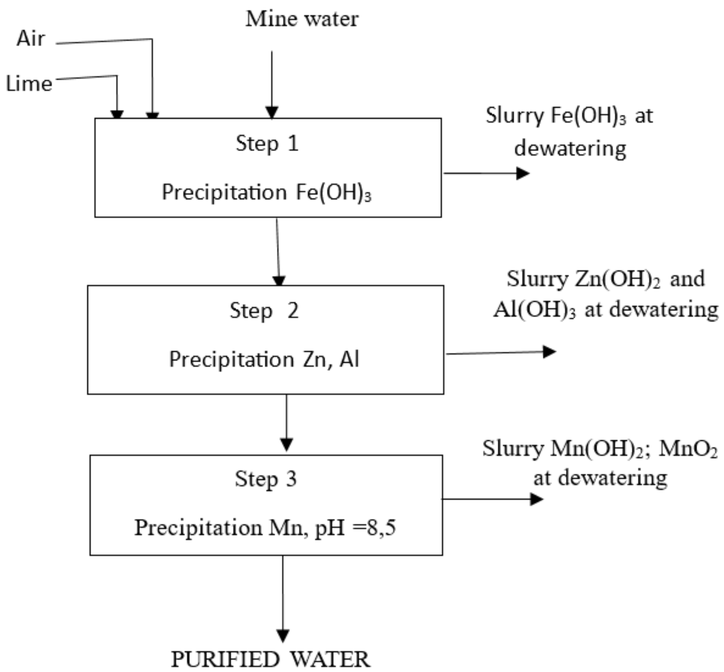

Figure 1. Technological flow of the sewage treatment plant from E.M. Herja

The two mine water treatment technologies generally ensure the removal of heavy metals through oxidation/precipitation processes and compliance with the imposed limits. It was found, however, that there are quite a few situations in which the removal of Mn may require a deprecipitation pH > 8.5.

By applying the lime treatment technology at pH < 8.5, the remaining concentrations of calcium and magnesium sulfates exceed the limits allowed by the NTPA - 001/2005 standard for calcium, magnesium (when present in mine water) and sulfate ion - the technology classic neutralization with lime not ensuring the reduction of these indicators to the normative values due to the high solubility of magnesium hydroxide (at pH <10.5) and calcium sulfate resulting from purification.[Thus, the concentration of calcium in purified water is usually higher than 400 mg/l, and the sulfate ion is found in the range (1500 - 2500 mg/l). The remaining concentration of magnesium approaches the initial one.

c) Passive purification technology for neutralization and precipitation of heavy metals

The technology of passive treatment of mine waters using limestone channels was applied for Bălan - Galeria Antoniu Sud in an experimental system, dimensioned for a flow Q max =20 l/s.

The purification technology is based on the passage of the mine water through a layer of limestone, which constitutes the passivation channel, where the reduction of heavy metal content in the treated mine water takes place through alkalization. Purification takes place through the co-precipitation of heavy metal ions from the mine water.[4],[13].

At the starting time, the passive treatment system showed a relatively good potential, the efficiency decreased, the purification yields becoming negligible over time due to the following phenomena:

- Mine water changed its quality, becoming less acidic (from pH ≈4.6 it evolved to pH ≈ 6.0 -6.70);
- Passivation over time of the limestone deposited in the channel;
- The manganese content in the mine water increased significantly; since manganese requires a high pH for precipitation, which cannot be ensured with limestonethe manganese retention yield is insignificant.

2.2. Technological concepts for the treatment of existing mine waters internationally

On the international level, there are concerns regarding the treatment of mine waters, research and implementation on an industrial scale, materializing in the following directions:

- active systems
- passive systems

a.Active systems for purifying acid mine waters

The active technologies for the purification of acid mine waters are based on a series of usual operations aimed to improving the quality of the mine water and respectively processing the solid phase obtained by precipitation (metal hydroxides, calcium sulfate).

- pH correction / precipitation: ensures the reduction of acidity and the rapid precipitation of metals in the form of hydroxides in one or more steps, depending on the composition of the water.

Usable mine water neutralizing agents:

- calcium hydroxide (the most used, it is also a coagulation-flocculation agent, it removes sulfate up to the solubility limit - $CaSO_4$) - BAT designation;
- sodium hydroxide (caustic soda is recommended in case of low flows of mine water, in isolated locations and for waters with high concentrations of manganese; sulfates remain in the soluble phase) - BAT designation;
- sodium carbonate: it is recommended in case of low flows, it precipitates existing calcium, it does not precipitate sulfates - BAT designation;
- quicklime/CO_2: removes sulfates up to the solubility limit of calcium sulfate, but the reaction speed is relatively low and the process is difficult to control in case of variations in the composition of the mine water;
- milk of lime/CO_2: wide field of applicability, robust technology frequently applied for mine waters, removes sulfates up to the solubility limit of calcium sulfate, presents the disadvantage of large volumes of sludge compared to the use of alkalization with quicklime (CaO) – BAT nomination;
- limestone, dolomite: removes sulfates up to the solubility limit of calcium sulfate, but the reaction speed is relatively low, does not ensure advanced precipitation of heavy metals (Cd, Mn, etc.) - BAT designation
- thermal power plant ashes/red sludge from the production of alumina (potentially recoverable waste), can bring additional pollution, act differently on sulfates;

In the case of mine waters with a high manganese content, in the context of the existence of discharge limits ≤ 1 mg Mn/l, the global precipitation of metals at pH > 8.5 (max 10.2) is generally used, followed by pH correction with HCl or CO_2.

- Sludge separation: lamellar decanters or flat decanters with or without addition are used

of flocculants; the "high density sludge" technology allows increasing the content of solid substances from 5% to 25-30% and is based on the recirculation of part of the sludge during the precipitation phase. In rarer cases, sand filtration is used as the last phase to separate the precipitates from the purified water.

The treatment with lime or sodium hydroxide/lime is also used within some complex technologies for removing the sulfate ion, regardless of whether it is sulfate removal techniques by precipitation or by membrane + precipitation techniques.

b.Passive systems for purifying acid mine waters

In the context of mine waters, the term "passive treatment system" refers to a wastewater treatment system that uses available natural energy sources such as: specific topography, microbial metabolism energy, photosynthesis and chemical energy.[8]

The main procedures for passive treatment of acid mine waters are the following:

- Aerobic wetlands
- Anaerobic wetlands
- Open channels with limestone
- Diversion wells
- Anoxic channels with limestone
- Successive systems producing alkalinity
- Vertical flow reactors
- Bioremediation

c. Combined technologies for treating acid mine waters

Multistage treatment (example: the pilot plant built in Great Britain near the Wheal Jane - Cornwell mine, the largest installation of this type in Europe) in which purification is carried out on three treatment lines, as follows:

1) Aerobic reed layers (remove metal hydroxides and arsenic);

2) Anaerobic cell (mixture of dung, straw or sawdust for anaerobic conditions) for bacterial sulfate reduction, with simultaneous elimination of Zn, Cd, Cu, Fe;

3) Aerobic filter with rock support, with algae stimulation/development (manganese removal).

Each of the three systems has a specific pretreatment step for pH correction with lime or limestone/lime. The mentioned procedures assume the removal of more or less calcium and sulfates, normal constituents of the pollution background specific to mining areas.

2.3. Technological solutions for mine water treatment with the integration of advanced sulfate/calcium ion removal

The processes of treating mine water with lime can ensure, depending on the working pH and the reaction time, reaching sulfate concentrations ≥ 1200 mg/l (with an increase in the concentration of calcium ions).Although there are few cases in which the removal of sulfate from mine waters was required in addition to the treatment process for these waters, for which the essential performance criterion is the advanced removal of heavy metals from the aqueous system, there are concerns that have materialized through the scale testing pilot or even on an industrial scale of some techniques to reduce the sulfate concentration.

Mine water treatment technologies with sulfate removal are poorly documented and existing consistent information is difficult to access. The treatment processes applicable for sulfate removal can be divided into four categories:

1. Chemical treatment with formation of insoluble compounds - precipitation with calcium aluminate or aluminum hydroxide at high pH (11.5-12); SAVMIN, Walhalla (CESR); Barium
2. Processes with reverse osmosis membranes (SPARRO), nanofiltration, electrodialysis (EDR)
3. Ion exchange GYP CIX (South Africa); Sulf-IX (Canada BIOTEQ)
4. Biological purification (Canada BIOTEQ, Western Europe, USA – biological processes)

The procedures that fall into the category of chemical treatment are: precipitation with lime or limestone, precipitation with barium compounds, such as ettringite using aluminum hydroxide or calcium aluminate with lime.

The membrane techniques are: reverse osmosis (applicable only in the SPARRO version with the introduction of gypsum sludge in the influent), nanofiltration and electrodialysis. Pretreatment of the influent and processing of the concentrate is necessary.[5]

Ion exchange techniques use ion exchange resins in single-phase or two-phase processes - metal precipitation followed by ion exchange. It is necessary to pre-treat the influent, and for the regeneration of the ion exchangers, bases and acids will be consumed in quantities equivalent to the ion loading of the process influent. Regeneration results in solutions (or gypsum suspensions in the case of the GYP CIX process) that require additional processing.

Biological processes use bioreactors or bioreactive barriers and require the addition of a reducer to the system (for example, a carbon source).

The chemical treatment of mine waters with lime or calcium carbonate is traditionally used for the precipitation of metals, but it also results in the precipitation of SO_4^{2-} in the form of $CaSO_4$.

The remaining sulfate concentrations are controlled by the solubility of gypsum, depending on the composition and ionic strength of the solution, in the range of 1500-2000 mg/l. Because residual sulfate concentrations are high, this process is indicated as pretreatment for mine waters with high sulfate ion contents. Sulfate precipitation using barium compounds uses $BaCl_2$, $BaCO_3$, $Ba(OH)_2$ and BaS. Barium hydroxide and barium sulfide are very effective over a wide pH range. The process is very efficient (residual sulfate in very low concentrations, simple operation, small volumes of sludge), but also very expensive.

Apart from economic considerations, the process is not widespread due to the toxicity of the barium compounds.[13].

The process that uses barium sulphide cannot be conducted at pH values in the basic range, because the water will be charged with sulphide, which is toxic. In fact, a precipitation process is proposed which is conducted at acid pH (injection of CO_2 in the reaction phase - sealed reactor and decanter), followed by air stripping of H_2S from the effluent. $BaSO_4$ resulting from precipitation follows a process of thermal reduction with the regeneration of barium sulphide. The hydrogen sulphide resulting from the process is oxidized to elemental sulphur. (fig. 2) [7],[15].

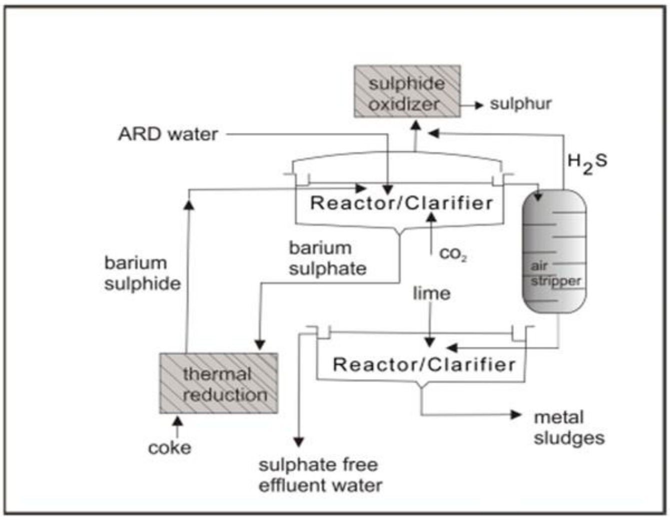

Figure 2. Technological scheme of mine water treatment with barium compounds

The sulfate removal processes from water based on ettringite production have been developed in two variants, SAVMIN and Walhalla (CESR), with or without ettringite processing in order to recover and reuse aluminum in the ettringite reaction-precipitation phase. (fig. 3)

Thus, the SAVMIN process uses several precipitation phases to remove sulfate from the soluble phase.[9].

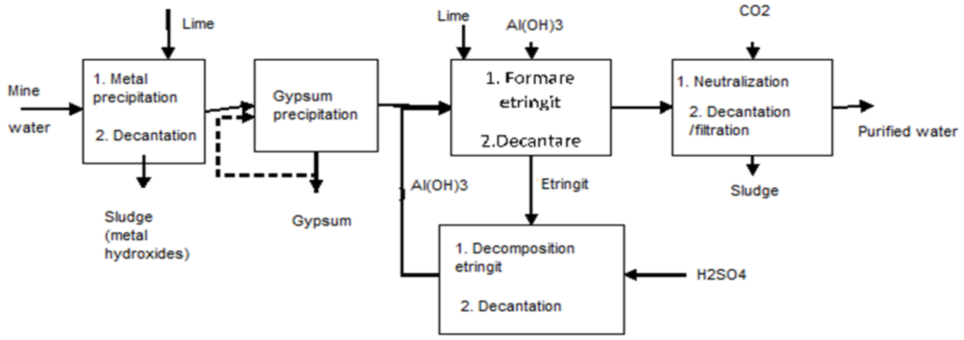

Figure 3. The sulfate removal process by precipitation as ettringite in the SAVMIN version

The main processes that take place are:

Phase 1:

$Me^{2+} + Ca(OH)_2 \rightarrow Me(OH)_2 \downarrow + Ca^{2+}$ (pH = 12)

Phase 2 (seeding with crystallization seeds required = recycled gypsum):

$Ca^{2+} + SO_4^{2-} \rightarrow CaSO_4 \downarrow$

Phase 3 – ettringite precipitation:

$6Ca^{2+} + 3SO_4^{2-} + 2Al(OH)_3 + 37H_2O \rightarrow 3CaO{\cdot}3CaSO_4{\cdot}Al_2O_3{\cdot}31H_2O \downarrow + 6H_3O^+$

$6H_3O^+ + 3Ca(OH)_2 \rightarrow 12H_2O + 3Ca^{2+}$

Ettringite is decomposed with sulfuric acid to regenerate aluminum hydroxide which is reused in the process:

$3CaO{\cdot}3CaSO_4{\cdot}Al_2O_3{\cdot}31H_2O + 6H_3O^+ \rightarrow CaSO_4 \downarrow + 3Ca^{2+} + 2Al(OH)_{3\,(S)} + 37H_2O$

The aluminum hydroxide is recovered by settling and recirculated, the phase followed by the seeding of the solution with gypsum crystals that cause the precipitation of gypsum from the solution. It is removed by filtration and decantation.

The SAVMIN process was verified on a pilot scale for flow rates of about 1 m3/h, obtaining final sulfate concentrations < 200mg/l for initial concentrations of 600-800mg/l.

The process without aluminum recovery (CESR or Walhalla) is similar to the one described above, calcium aluminate being used for ettringite precipitation. If it is desired to separate the dangerous sludge from the non-dangerous one (gypsum + ettringite), it is necessary to operate in stages: precipitation/separation of gypsum at a moderate pH (sludge considered non-dangerous), precipitation of heavy metals and gypsum at pH=10.5 (dangerous sludge), ettringite precipitation (pH=11.5) and final pH correction with carbon dioxide. The CESR process allows reducing the sulfate concentration to < 100mg/l, starting from initial concentrations of the order of thousands of mg/l.

The reverse osmosis process can produce a very good effluent quality, but its applicability in mine water treatment is reduced due to the high calcium and sulfate contents that severely affect the degree of water recovery (30-70% depending on the source of information). Other dissolved species, aluminum, zinc, iron cause membrane clogging if the influent is not pretreated initially.

The operating cost of the process (disregarding pretreatment) is mainly given by the consumption of electricity for pumping, the recovery of the effluent energy through turbine-type devices - electricity, pump actuation, etc. being preferable. Osmosis operates at about 50 bar.

Reverse osmosis can become attractive for waters with a lot of calcium and sulfate in the variant with the seeding of the influent with gypsum crystals (SPARRO Slurry Precipitation and Recycle Reverse Osmosis or Seeded RO) in which a recycled sludge (gypsum 3-10% su) is introduced into the supply system to provide nucleation centers for the precipitation of gypsum and other minerals, which prevents precipitation on the membrane. (fig. 4.)

The SPARRO process mainly consists of:

- pretreatment by pH correction with bases, precipitation, flocculation, decantation, filtration, clear water storage;

- reverse osmosis, the concentrate being sent partially for separation in a hydrocyclone and partially in a reactor in which the precipitation of gypsum from the supersaturated solution is also induced (reaction time approx. 1h).

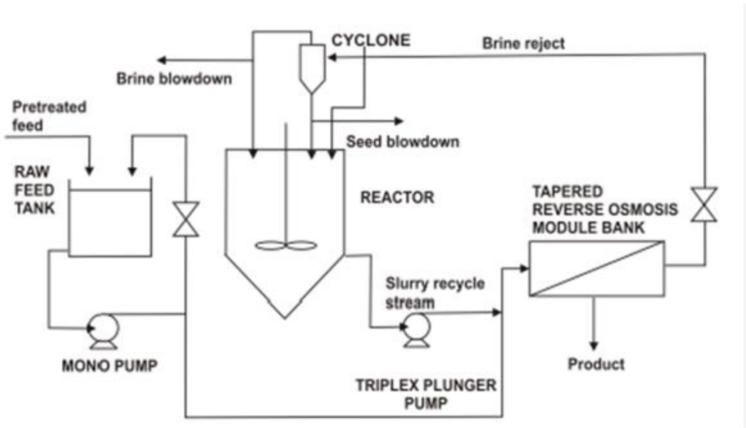

Figure 4. Technological schem of reverse osmosis process

The reverse osmosis process was, for example, applied in a study to reduce sulfate from 6600 mg/l to 152 mg/l for flows of about 3m3/h, but the mechanical failure and clogging of the membranes led to the shortening of the lifetime under projected values.

As an alternative to reverse osmosis, there is the nanofiltration process that can be operated at lower pressures, around 20 bar, and has the advantage of a water recovery rate of around 75%. Applications of the process are known to remove sulfate from brine in electrolysis processes and to remove sulfate from injection water for drilling.

Membrane processes based on ion-selective membranes - electrodialysis do not require operation at high pressures, but use direct current electricity. An electrolysis installation will only work with pre-treated water, to avoid clogging the membrane and clogging the passage spaces between the compartments of the electrodialysis module. In operation, a pilot electrodialysis installation can process, for example, approx. 6 m3/h of sulfated water, reducing the fixed residue / sulfate concentration from 3200 mg/l / 74 mg/l to 640mg/l / 5 mg/l. Ion exchange procedures were not required in the treatment of mine waters for sulfate removal, with the exception of the GYP-CIX process (cationite-degasser-anionite system in fluidized bed in several stages) which uses $Ca(OH)_2$ 2% for regeneration and H_2SO_4, with gypsum as final product. The biological processes of sulfate removal are based on certain microbial communities ("sulfate reducers") that can use sulfate as an oxidant for energy production. For this process the presence of a reducing substrate is necessary. In these processes, under conditions where the microorganism growth space is anoxic (O2 < 0.1mg/l), the reaction product is elemental sulfur. The existence of stronger oxidants than sulfate, such as Fe^{3+} or NO_3^-, will affect sulfate reduction.

3. CONCLUSIONS

Regarding the quality of mine waters from non-ferrous metal mining, a great variability of the impurity matrix from one source to another and a variability over time for the same source was found.

Mine waters fall into one of the following categories:

A. The category of highly charged mine waters, mostly in the concentration range of hundreds of mg/l

B. Category of mine waters with medium loading (tens – hundreds of mg/l)

C. Category of mine waters with low load (< 10 mg/l)

D. Category of mine waters with very low load (NTPA 001 compliance)

To remove sulfate from mine waters in general, pretreatment is necessary (precipitation technology with lime and limestone). Sulfate removal techniques from aqueous systems must be adapted for the specificity of mine waters;

All processes lead to the formation of chemical sludge (depending on the pretreatment option, the sludge can fall into hazardous or non-hazardous categories).

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RESEARCH ON THE USE OF ROCKS IN ROAD INFRASTRUCTURE

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Abstract: *The possibility of using rocks in the field of road construction is regulated by a series of standards that require the fulfillment of certain criteria that rocks must meet in order to be used in this field. The use of rocks in the construction of infrastructure for land communication routes is only allowed if they fall within certain grading classes.*
The use of rocks in the execution of infrastructure for land communication routes: highways, roads and railways is allowed only if they meet certain quality criteria. In the Laboratory of Analysis and Testing in Construction of the University of Petrosani, the geomechanical properties of rocks to be used in construction were determined and compared with the limit values imposed by the standards in force. The geomechanical characteristics of the mining perimeters Brănișca, Săcărâmb, Almașul Mare, Dobra, Căzănești, Săvârșin, Șoimoș Lipova, Cerbia Zam, Certej Valea Căpitanului and Certej-Floroaia Toader were determined.

Key words: Geomechanical caracteristics, Quality coefficient, Rock class Admissibility conditions

1. GEOMECHANICAL PROPERTIES OF ROCKS

Geomechanical properties were determined for the rocks under study, which are stipulated by the standards in vigor. [1], [2], [3]. [4], [5], [7].

The results are given in Tables 1, 2 and 3.

Table 1. Physical properties of rocks

Type of rock	**Collection point**	**Volumeetric density γx10⁴[N/m]**	**)rosity %]**	**Moisture W[%]**	**Water retention %**
Adamelitic Granite	Șoimoș Lipova	2,764	0,824	0,048	0,415
Adamelitic Granite	Șoimoș Lipova	2,762	0,832	0,064	0,411
Gabrou with diopsid	Cerbia Zam	2,658	0,748	0,215	0,012

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Granite Porfiroid	Valea Căpitanului	2,6240	0,8225	0,143	0,2988
Andezit	Brănișca	2,7046	0,3242	0,514	0,104
Andezit	Almașul Mare Albini	2,6734	0,6831	0,351	1,1652
Andezit	Certej- Floroaia Toader	2,4674	0,412	0,178	3,3578
Gabrou	Căzănești,	2,8450	0,730	0,235	0,5407
Bazalt	Dobra	2,701	0,880	0,154	0,521
Granite	Săvârșin	2,519	0,797	0,137	0,3888

2. MECHANICAL PROPERTIES

The use of rocks in the infrastructure of terrestrial communication routes is conditional on the fulfillment of minimum quality requirements. In order to fulfill the quality conditions the rocks have to be tested under different mechanical stresses. Thus, for the analyzed rocks, the following important characteristics were determined: compressive breaking strength in dry, saturated and after freeze-thaw cycles; crushing strength in dry and saturated state; freeze-thaw strength; softening and gelivity coefficients.

All the results were processed and interpreted on the basis of the engineering experience of the research team of the Analytical and Testing in Constructions of the University of Petrosani. The results of these properties are summarized in Table 2. [7], [8]. [9], [10], [11], [12], [13]. [18].

Table 2. The property of the mechanical rocks

Rocks name/collection point	**Compression resistance σrc[MPa]**			**Crushing resistance [%]**		**Saturation softening coefficient η[%]**	**Gelability coefficient [μg]**
	The condition of the specimen			**Condition**			
	Dry	**Saturated**	**Freeze >thaw cyles**	**Dry Rcu**	**Saturated Rcs**		
Adamelitic Granite / Șoimoș Lipova	160,78	150.30	148,9	90,5	87,5	0,069	0,101

Adamelitic Granite / Șoimoș Lipova	164,35	154,2	150,48	92,4	88	0,059	0,11
Gabrou with diopsid/ Cerbia Zam	165,91	158,95	138,18	83	80	0,043	0,0647
Granite Porfiroid/ Valea Căpitanului	151,33	141,19	139,25	90,4	89	0.0718	0,117
Andezit/ Brănișca	154,28	147,55	143,28	95	89	0,0456	0,0767
Andezit/ Almașul Mare Albini	162,32	157,29	145,25	98	93	0,0319	0,1175

3. TECHNOLOGICAL PROPERTIES

The analyzed rocks, to be used in the earthworks of highways, roads and railways, must meet the following technological properties: wear resistance, quality coefficient, rock class and abrasivity, and their results must comply with the standards in force. The values of these properties are given in Table 3. [14], [15], [16]. [17], [19].

Table 3. Technological properties of rocks

Type of rock	Wear ressistance Ruz[%]		Abrasivenes of rocks a[mg]	Quality coefficient C	Rock class	Obervation
	Los Angeles	Deval				
Adamelitic Granite/ Șoimoș Lipova	15,4	2,43	18	17,31	A	Excellent
Adamelitic Granite/ Șoimoș Lipova	14,5	2,45	21	18,6	A	Excelllent
Gabrou with diopsid/ Cerbia Zam	15,9	2,65	19	17,02	A	Excellent
Granite Porfiroid/ Valea Căpitanului	15,4	2,56	15	19,8	A	Excellent
Andezit/ Brănișca	14,5	2,03	20	18,77	A	Excellent

Andezit/ Almașul Mare Albini	15,8	2,15	15	18,6	A	Excellent
Andezit/ Certej-Floroaia Toader	15,2	2,5	12	16	A	Excellent
Gabrou/ Căzănești,	15,8	2,155	17	18,56	A	Excellent

4. ELIGIBILITY CONDITIONS FOR ROCKS

Petrographically the rocks must be homogeneous, with no visible signs of physical or chemical alteration, free from microcrystalline or amorphous silica which may react with alkali in cement. The rocks must be magmatic, granite, granodiorite, rhyolite, dacite, syenite, diorite, andesite, andesite, diorite, gabbro, basalt, diabase, metaphyre, metamorphic, amphibolite, quartzite, gneiss, crystalline and sedimentary limestone, limestone, dolomite, siliceous sandstone and breccia.

Rocks used to produce natural stone products are classified into five classes A, B, C, D, E, according to their main intrinsic geomechanical characteristics, as shown in Table 4.

Table 4. The admissibility conditions of the source rocks

Geometric feature	**Rock class**				
	A	**B**	**C**	**D**	**E**
	Admissibility conditions				
Apprent porosity at normal pressure, %, max.	1	3	5	8	10
Dry compressive strenght, N/mm^2, min.	160	140	120	100	80
Wear and tear with Los Angeles type machine %, max.	16	18	22	25	30
Resistance to crushing by compression in the dry state %, min.	70	67	65	60	50
Resistance to freezing and thawing	3				
Gellitivity coefficient 25) ,%,max. Sensitivity to frost (25), %, max.	25				

Rocks that do not meet the admissibility conditions for freeze-thaw resistance should not be used in road works. As can be seen, all the analyzed rocks fall into class A according to Table 3 and can be used without restrictions in the infrastructure of land roads.

5. CONCLUSIONS

1. The geomechanical characteristics of the analyzed rocks were compared with the admissibility conditions imposed by the standards invigoare.

2. The following conclusions can be drawn from the experimental data and the comparison of the values obtained with the admissibility conditions:

3. The magmatic rocks analyzed are those that meet the admissibility conditions.

4. The compressive breaking strength, ranging from 151.10 to 165.91.

5. Water saturation softening coefficient, between 0.0245 and 0.0718.

6. The coefficient of gelivity is between 0.0567 and 0.1175. This shows that the influence of water and temperature variations are negligible.

7. The coefficient of quality of these rocks recommends them for use in the infrastructure of terrestrial communication routes and road embankments.

8. The analyzed rocks are abrasive or medium abrasive, and the wear resistance and quality coefficient are within the limits of admisibility.

9. All analyzed rocks belong to category A in terms of road type and are suitable for highways.

10. The analyzed rocks are of excellent sound quality;

11. The rocks analyzed in the Laboratory of Analysis and Testing in Constructions of the University of Petrosani, meet the conditions of admissibility and can be used in the infrastructure of land roads.

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GEOMECHANIC RESEARCH REGARDING QUALITY OF ROCKS USED FOR REHABILITATION OF TREATMENT PLANT FOR INDUSTRIALLY USED WATERS

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Abstract: *Water quality is mostly affected by polluting materials deversations and infestations by humans and institutions. As a result, it is crucial (as a main practical measure) to find the most adequate solutions to treat wastewater infested with diverse pollutants. The main objective of water treatment is removal of toxic substances, microorganisms and bacteria, for sustainable development of human society, because of adequate measures of environmental protection.*

Wastewater treatment is done through different methods: mechanical (primary), biological (secondary) and advanced (tertiary). For every method, it is ensured the retention of different substances from wastewater, using physical methods (for mechanical treatment), chemical (for chemical treatment) or biochemical (for secondary and tertiary treatment). Associating the three treatment phases is conceived to obtain extra yield of removal of existing impurities from untreated wastewater, to reintroduce them in the nature surface water circuit, respecting the parameters from the actual technical norms. Industrial development pushed researchers to find new more efficient processes for wastewater treatment. Biological filters and aeration basins with activated sludges were built. To obtain better efficiency, water treatment, urban wastewater treatment became very specialized technology.

Key words: *wastewater plant, wastewater, soil*

1. GEOMECHANICAL PROPERTIES

Mechanical methods consist of retaining insoluble substances in wastewater. Considering size and weight, those substances are retained in the following constructions and installations: grates, screens, sand removers, grease separators and decanters. [1], [2], [3].

These deposits are removed and stored in a fresh state or are processed through fermentation and dehydration to modify their toxic, viscosity, smelly, looks and humidity grade.

After passing through mechanical treatment works, suspension materials from wastewater are reduced by 40-65% and BOD5 is reduced by 25-40%.

Wastewater must be mechanically treated in any drainage system and for any emitter. If the treatment level regarding BOD5 or dissolved oxygen is less than 25%, there will be no further biological treatment required.

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2. BIOLOGICAL PROPERTIES

Biological methods or secondary consisted of retaining the colloidal and dissolved substances from sewage waters. Also, in aerobically mineralization of the organic substances retained. Soluble substances which are passed through mechanical processing are retained by the biological treatment steps. Partially, the substances which were transformed will be dissolved in water and remain as harmless substances carried away by the water stream. Another part is deposited or is released as gases.

Biological treatment is made by degrading the organic chemical compounds, under the action of microorganisms, with the presence of dissolved oxygen and transforming these compounds in non-toxic substances. [7], [8], [9].

In the actual concept and practice, biological treatment of wastewater is not a unique operation. It is a combination of intermediary operations, which depend by the water characteristics and requirements of outflow from the emissioner.

The chemical processes scheme of degrading the organic substances can be represented like this:

$$\text{Simple organic substance} \xrightarrow[\text{Bacterial cell}]{O_2} CO_2\text{+Simpe organic substance}$$

Cellular material

Figure 1. Chemical processes scheme (degrading organic substances)

The oxidation of the organic substance is made in successive steps, each step being catalysed by specific enzymes and consisting of the molecular transfer of hydrogen from the substance to an acceptor, until the last hydrogen acceptor is occupied. In our situation, in anaerobic conditions, the acceptor is oxygen.

Written as a chemical formula, this phenomenon which takes place during the formation and destruction of activated slums is as follows:

$$CnHmOpNr= nCO_2+ m/2\ H_2O + r/2\ N_2 \qquad (1)$$

In these reactions, the main output is CO_2 and H_2O. As a tertiary byproduct, the result is a new cellular layer, which is capable of degrading other organic molecules.

In the biological treatment process, besides the added assimilable organic substances, the existence of the elements which are indispensable for life, like nitrates and phosphorus. Considering the literature data, the nutritive substances content, reported to CBO, is the minim of CBO:N:P=150:5:1 and maxim of CBO:N:P= 90 :5:1.

The biological treatment, in artificial conditions, is made in aeration basins plus low and high-capacity filters. The biological filters, which have lower loading capacity, work with complete treatment. High-capacity ones and aeration basins work with complete or incomplete treatment. For the complete treatment, CBO5 is reduced by 75 - 90 % and for the incomplete one is reduced by 40 - 50 %. For the complete treatment, the bacteria are reduced by up to 90 - 95 %.

3. THE TREATMENT SCHEME ADOPTED

After the technological processes from S.C. Fabrica de arme Cugir, the resulting waters are collected in the septic basin and the settling basin which are situated in the West side of the company. The total capacity of these basins is around 150 m^3. These waters get here through a sewage network and pipes with a diameter of 300 mm. [1], [7], [8].

After the analysis made by the Alba Environment Protection Agency, it resulted a series of exceedances of certain indicators like suspension material, ammoniacal nitrogen, synthetic detergents, total cyanides, copper.

The results of these analysis are in table 1.

Table 1. Analysis results of outflow water

Nr.	Indicators	Units	Results	Maximum admissible limit
1.	pH	upH	6.48	6.5 – 8.5
2.	Suspension material	mg/dm^3	243	35
3.	Ammoniacal nitrogen	mg/dm^3	19,866	2.0
4.	CCO - Cr	mgO_2/dm^3	28.13	125
5.	Synthetic detergent	mg/dm^3	11.16	0.5
6.	Extractible substances	mg/dm^3	11	20
7.	Ionized Iron total (Fe^{2+}, Fe^{3+})	mg/dm^3	4.6	5.0
8.	Total cyanide (CN)	mg/dm^3	0.368	0.1
9.	Nickel (Ni^{2+})	mg/dm^3	0.48	0.5
10.	Total chrome (Cr^{3+}, Cr^{6+})	mg/dm^3	0.022	1.0
11.	Total phosphorus (P)	mg/dm^3	0.7	1.0
12.	Copper (Cu^{2+})	mg/dm^3	3.85	0.1
13.	Free residual chlorine	mg/dm^3	0.12	0.2
14.	Sulphides and hydrogen sulphide	mg/dm^3	0.115	0.5
15.	Chlorides (Cl)	mg/dm^3	101.6	500.0

From the analysis of the results, it is found that the maximum limits allowed for discharge by NTPA 001, modified and completed by Government Decision nr. 352/2005 for these indicators:

- Suspension materials: by 6.9 times;
- ammoniacal nitrogen: 9.9 times;
- synthetic detergents: 22.3 times;
- total cyanides: 3.6 times;
- copper: 4 times.

After results interpretation, there were more treatment schemes tested. Then, analysis was requested by the Environment Agency for the implemented scheme.

Advanced purification of these waters will be achieved through physio-chemical processes, as the next scheme shows, figure 2:

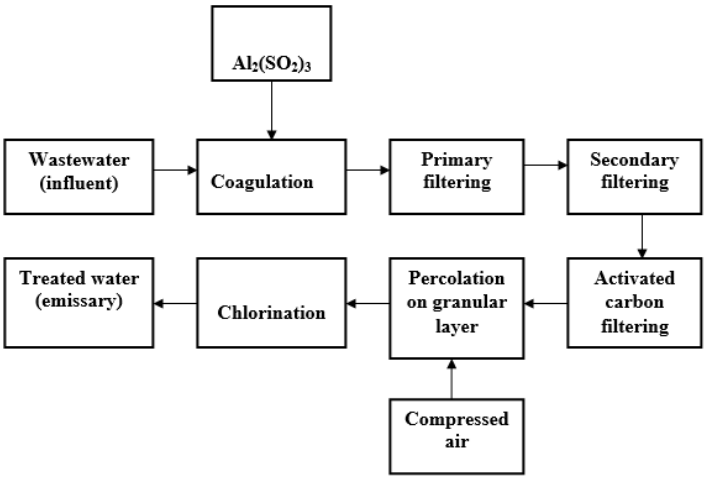

Figure 2. Schematics for wastewater processing at S.C. Fabrica de arme Cugir

4. TECHNOLOGICAL PROPERTIES

Very fine colloidal materials and suspended matter can only be removed from wastewater if they are made sedimentable, through adding coagulants. These are chemical substances which are dispersed in water, as fine particles, charged with a positive electrical charge, neutralizing the electrical field of natural solid particles in colloidal suspension. The effect of this phenomenon is that fine particles agglomerate in the form of increasingly larger flakes, due to the so-called flocculation process. And those, through the action of gravity, are deposited on the bottom of the settling basins, in which the process occurs, entraining at the same time the non-agglomerated particles. The combination of the flocculation and sedimentation processes is called chemical precipitation. [4], [5], [7].

The coagulants usage for wastewater treatment is less common than for feedwater treatment. For wastewater, the usage of reagents is recommended when:

- these waters have big seasonal variations for flow, suspension concentration or degree of purification;

- a higher degree of purification is required than the one obtained through normal sedimentation;

- the area occupied by the treatment plant is small; it is necessary to avoid the production of unpleasant odours;

- industrial wastewater contains substances that needs to be removed, being inhibitors for the biological treatment;

Lately, the interest for using coagulants increased, for urban wastewater and even more for industrial wastewater.

The most cost-effective chemical substances used for coagulation are iron salts and aluminium salts. These are: ferric chloride FeCl3, ferric sulphate, ferrous sulphate, aluminium sulphate and lime in the form of calcium oxide CaO or calcium hydroxide Ca(OH2) for correcting the pH of wastewater.

Chemical treatment through coagulation-flaking leads to the reduction of organic substances expressed as CBO5 of approx. 20-30%, allowing the avoidance of excessive loading of the activated slums with organic substances.

The main agent in the coagulation-flocculation process is the Fe3+ ion, which is obtained by oxidizing ferrous sulphate or aluminium sulphate with sodium hypochlorite. The lime milk that is added together with the ferrous sulphate or aluminium sulphate, has the role of accelerating the formation process of flocculation and settling of the precipitate formed.

The oxidation reactions of Al2(SO4)3 (aluminium sulphate) and FeSO4 (ferrous sulphate) are:

$$Al_2(SO_4)_3+3Ca\ (OH)_2+Cl_2=2Al\ (OH)_2+2Ca\ (SO_4)_3+CaCl_2 \quad \textbf{(2)}$$

$$2FeSO_4+3Ca\ (OH)_2+Cl_2=2Fe\ (OH)_3+2CaSO_4+CaCl_2 \quad \textbf{(3)}$$

Removal through decantation of the formations, is necessary as they could prevent the biochemical oxidation processes from taking place, through blocking the biocenosis` metabolic exchange surface.

The chemical coagulation contributes to phosphorus and nitrogen removal. Phosphorus is one of the important elements which leads to eutrophication of the varnish.

Both ferric chloride and aluminium sulphate are recommended for phosphates removal, with the condition that these are properly agitated to ensure the formation of flakes and adequate timing for reaction and decantation.

The simultaneous coagulation with ferric chloride and lime, got pH of 8.8-9 and leads to almost complete removal of the phosphor from wastewater. The advantage of simultaneous usage of these two coagulants, consists of the quantity reduction of ferric chloride (which is costly). And increases the efficiency of phosphor removal.

For phosphor elimination through chemical methods, can be used 2 processes:

- simultaneous precipitation;
- posterior precipitation.

For the first procedure, the ferric chloride is added directly in the aeration basin which contains the activated slums. The recirculation slum and the excess one, allows to be used that excess iron which it contains. It also favours the phosphates precipitation, and, as a result, it is reduced the quantity of ferric chloride.

The ferric chloride economy is 50-70% compared to what it would be necessary if there would be no recirculation.

In the second process, phosphates are precipitated after the secondary decantation. For this, a reagent plant with all the necessary compartments (preparation, mixing, reaction) is placed after the secondary decanter, thus creating a proper tertiary treatment plant.

The research regarding water coagulation is made after the „Jar Test" method, in a device which is made of a support for 4-6 cylinders of 1 Liter each. In this it is introduced the water, with the coagulant, which can vary. For example, from 5 to 5 mgf/dm^3. The device has a motor for agitation. At start, for 3-5 minutes, the water from the cylinders is agitated with high speed (approx.. 150 rot./min), which is needed for flaking the suspension matter. Then, for 30 minutes there is a waiting period, for the sedimentation of the contents of the cylinders, determining the turbidity of the cleared water. The probe in which the turbidity is lower, determines the optimal coagulant dose.

After the probes and the studies made, the optimal coagulant dose will be of 8mg for 10 Liters of water, or 0.8 kg /m^3 of water for the entire basin.

5. ADMISSIBILITY CONDITIONS

Contact filtering in the wastewater treatment technology, is recommended, in case the fine and colloidal particles is required. [6], [8], [9]. [10].

Filtering the wastewater is a physical method, generally used when superior quality is required, for the effluent, or when the wastewater is reused.

Inside the wastewater treatment plant, from the electrostatic painting section, will be used 4 contact filters, monolayer and multilayer, with descending filtering and free level.

For maximum efficiency, the resulted water from the treatment process will be stored in a basin and will be reused in the technological processes, from the electrostatic painting section. So, the result is a closed circuit, which does not affect and does not pollute the environment.

In the last step, will be used percolation, dry filtering, as a method to make the water clearer, with the help of a free descending level filter and with ascending air added in the ascendant stream. This way, suspension is retained, with biological effects and nitrogen reduction is assured.

The air introduced stimulates biological aerobic processes, throughout the entire thickness of the filter layer. This increases the efficiency of the clarification process.

During the filtration process, substances and particles which are in wastewater, which are retained in the filtering medium, causes the pores to shrink and get clogged. As a result, the increase in interstitial velocities leads to increased pressure losses through the filter, to a deterioration of the filtered water and even to a reduction in the flow rate. When these values exceed the permissible limits, the filtration process stops. After this, the filtration process stops and then the filter material is washed or regenerated.

The washing of the filter material will be done through the transmission of ascending water flow, or water and air, with speeds much higher than the ones used for filtration.

During the washing process, there are 3 steps. First, the filter bed is loosened, followed by the detachment and removal of the particles from the filtering material granules. This is done under the effect of intergranular friction. Then, these are transported by the ascending water stream.

The combined washing of the filters, with water and air, is contributing to almost completely removal of the retained suspensions but also reduces with about 50-60% of the washing water.

Both the intensities and the durations of washing will be set directly, through successive trials.

The water used for washing the filters, will be reintroduced in the clearing circuit, before getting to the primary decanter.

6. CONCLUSIONS

1. The particles in suspension as well as the granules of the filtering medium are charged with electronegative charges. To break the energy barrier created and for the fixation to take place, it is necessary that the particles to have extra energy at its disposal. Caused by one of the transport mechanisms. This would take them near the granules, for the molecular attraction forces to be able to act. Or that the potential energy of the particles to be very small, when compared to the potential energy of the granules, to be able to generate attraction forces.

2. The important problem, when the treatment plant is built, is represented by the large quantity of decanted material, 14 tons per month, resulted from the water coagulation process. This must be periodically collected and taken for neutralisation by a specialized company.

3. Technological wastewater results from the pickling phase of the metal door accessories. Also results from the aqueous liquids, resulted from the rinsing operations of the parts, after the nickel and chrome plating phases.

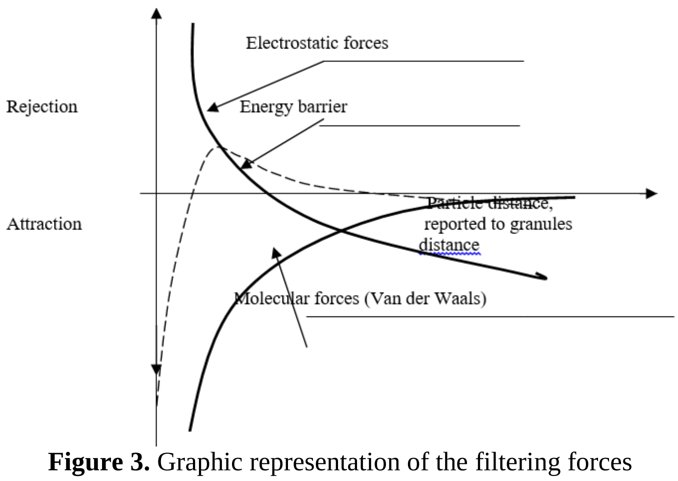

Figure 3. Graphic representation of the filtering forces

4. Wastewater collected in the metal coating section of door accessories, is collected through floor channels. From there, it is discharged into a reinforced concrete basin, with 2 compartments. Then, passes further, through the neutralization plant.

5. Through application of advanced and highly effective purification methods, which can remove the substances which are refractory to classic processes, we can obtain very good quality water. The discharge of such water into a drain, would not be rational, especially since it is obtained exactly where water shortages are felt the most and where the quality of the water from natural sources is closer and closer to admissibility limit.

6. Following the experiments we made, respecting the purification scheme, as well as the chemical analysis made by the authorized laboratory of the Environment Protection Agency from Alba County, it was found that the respective waters, after purification, fell within NTPA 001 quality indicators. The maximum admissible values were below the limit written in this regulatory act.

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INVESTIGATION OF THE DEFORMATION MECHANISM OF OPENING AND PREPARATION WORKS IN THE LIVEZENI MINING AREA

Cătălin Marian NISTOR[1], Ladislau RADERMACHER [2], Cristina Tamara DURA[3], Ramona NISTOR [4]

Abstract: *In the process of extracting underground mineral resources, it has been observed that the extraction methodology and the spatial progression of mining directions exert a significant reciprocal influence on both existing and contemporary mining works. The purpose of these studies aim the stability and durability of the Livezeni Mining Area. This study also aims to explore and elucidate the mechanisms through which new underground extraction activities impact existing mining structures. The primary objective is to identify effective strategies for managing rock pressure, thereby maintaining the geometric integrity of both existing and newly constructed mining gallery profiles and works. This approach seeks to ensure an optimal balance between extraction efficiency and the structural conservation of the underground environment.*

Keywords:*inclined shaft, heading gallery, rock pressure, mining panel, coal.*

INTRODUCTION

The main objective of the present work is the investigation of the rock pressure and the mechanisms through which new underground extraction activities impact existing mining structures. The opening and preparation works for investigation are:

1. Inclined Shaft from the extraction block placed in the rocks of the layer 3 of coal deposit. The extraction block represent the delimitation of the coal deposit proposed for extraction;
2. Inclined Shaft used for ventilation process placed under the crushed rocks in mining panel 3 – 4, layer 3 of coal deposit;
3. Heading Gallery from the mining panel number 5, layer 3 of coal deposit;

The studied perimeter is located in Romania as shown in Figure 1, as part of the East of the Autohton. In the half of the East, in Vulcan and Parâng mountains, the sedimentary deposits on this Autohton were stuck together, crushed and part metamorphosed under the pressure of the layers deposits that came above them, during the medium cretaceous movement.

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The Petroșani basin includes coal deposits that form one of the most important deposits for Romania. This tertiary age basin (Aquitanian) is situated over the Getic Crystalline, in the upper flow of the Jiu River where it forms a triangular trough with a ENE-VSV elongation.

Regarding the high thickness of deposits from the Petroșani basin that is over *800 m* it is easy to understand that for their sedimentation to take place the basin should have been continuously sinking. The sedimentary cycles were not continuous but in a rhythmic mode that allow the change of bionomics conditions of the basin and this is the case of subsidence.

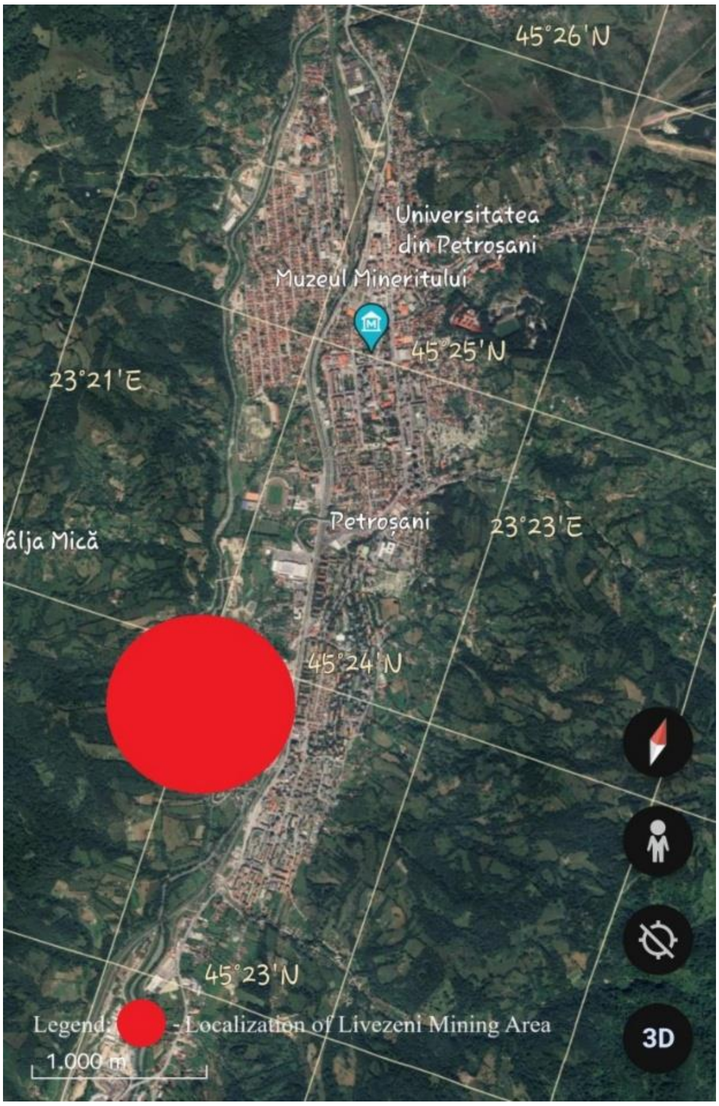

Figure 1. Localization of Livezeni mining area (source: Google Earth)

1. INVESTIGATION OF THE DEFORMATION MECHANISM FOR THE INCLINED SHAFT FROM THE EXTRACTION BLOCK PLACED IN THE ROCKS OF THE LAYER 3 OF COAL DEPOSIT

The inclined shaft was made for preparing and collecting the coal production from the extraction of the layer 3. The reason for the construction of this inclined shaft was that the old one remained in a advance state of degradation and it`s safety pillar was extracted in the mining panel limits of 3-4 and 1-2. A longitudinal section through the block of coal extraction is illustrated in Figure 2.

For reducing at minimum, the influence of the coal extraction fronts and regarding to ensure the stability for the new collecting inclined shaft, this was placed in the bottom of the layer 3 of extraction where the rocks are composed by compact limestone with a compression strength of *500* to *600 daN/cm*^{2} on a distance of *30 m* from the layer.

The collecting inclined shaft makes the connection between the main gallery, mining panel number 5 and the crosscut from the 475 horizon.

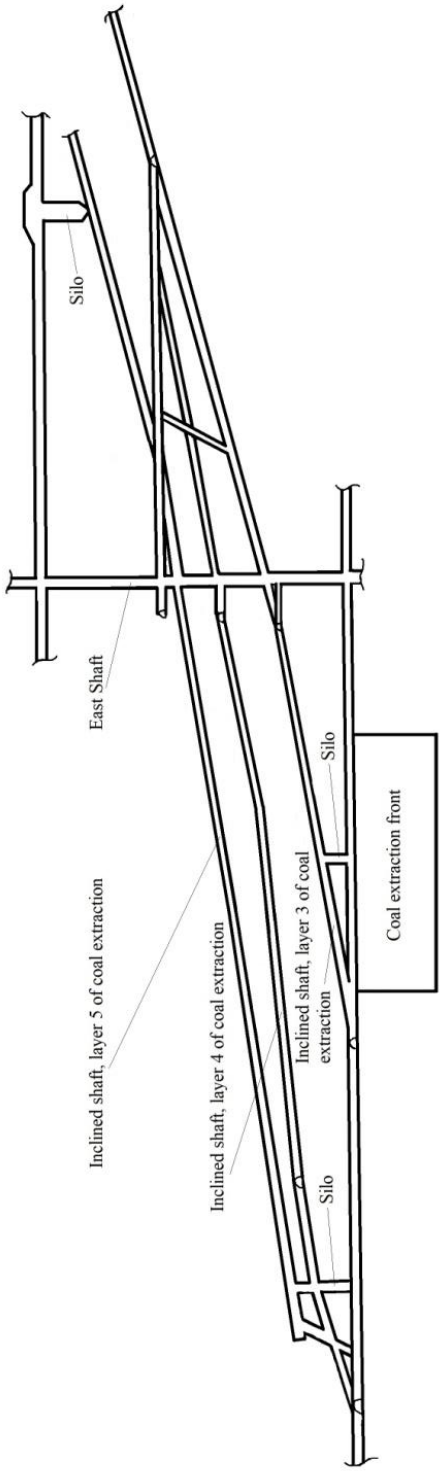

Figure 2. Longitudinal section through extraction block

The length of this inclined shaft is *230 m* and it`s mining support was executed from metallic profiles named SG-23, each frame being placed at a distance of *0,6 m* from one to another. The mining support usable terms that we use in this paper are described in Figure 3.

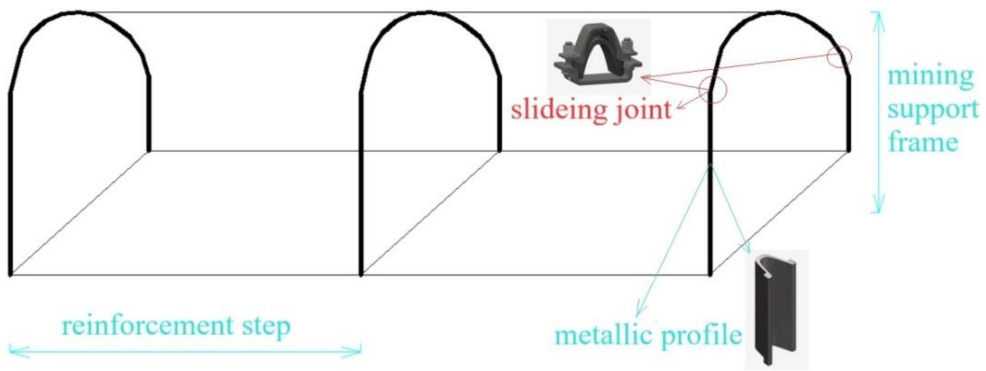

Figure 3. Mining support usable terms

From the observation and measurements made at this mining construction the next conclusions were obtained:

- in the first *4 months* of extraction the inclined shaft maintain it`s usable section and even if the mining support had the ability to slide in it`s joints the usable section remained unchanged;

- the increasing of the rock pressure and the first slide of the metallic profiles in their joints appeared after *4 months* at the connection of the inclined shaft with the coal silo and with the main gallery from horizon 475;

- at the connection of the galleries mention above, the inclined shaft mining support made of metallic profiles presented slides in their joints with the value between *5* to*15 cm*. The sliding joints of the metallic profiles from the mining support determines the convergence of the usable section of the investigated gallery. The joints of the metallic profiles have a articulation role from a constructive point of view and are two in total, one on each side. The usable section suffered a decrease of *0,8* m^2 after the sliding;

- at the connection of the inclined shaft with both the heading gallery and with the main gallery the convergence of the mining support didn`t record any irreversible deformations at the walls and ceiling at any of the frames;

- between the connections of the inclined shaft, the convergence of the mining support measured were minimum and at some frames were inexistent. Between the connections of the inclined shaft the maximum value of the mining support convergence was *5* to *6 cm*.

2. INVESTIGATION OF THE DEFORMATION MECHANISM FOR THE INCLINED SHAFT USED FOR VENTILATION PROCESS PLACED UNDER THE CRUSHED ROCKS IN MINING PANEL 3 – 4, LAYER 3 OF COAL EXTRACTION

Because of the fact that the old open-pit mining works were in advanced state of degradation, a new inclined shaft was needed to ensure the ventilation in the extraction front from mining panel number 5, layer 3. The inclined shaft for ventilation makes the connection with the heading gallery of the mining panel and with the ventilation main gallery from the horizon 550. The inclined shaft was placed in the section II of layer 3 under the rocks that collapsed during the extraction of the coal from the section I, mining panel number 3 and 4.

The length of the inclined shaft is *202 m* and was executed in the extraction layer with the metallic profile beam from the ceiling tangent at the collapsed rocks, as it is show in Figure 4.

From the observations and measurements of the convergence, the next facts were concluded:

- the convergence maximum values were recorded at the edges of the inclined shaft used for ventilation;

- at one edge, where the connection of the inclined shaft with the heading gallery took place, the convergence recorded a value of maximum $3{,}2\ m^2$ which means that the usable section was reduced with *28%*;

- at the connection of the inclined shaft with the main gallery use for ventilation the convergence recorded a value of maximum $3{,}9\ m^2$ which means that the usable section was reduced with *34%*;

- from the measurements and observations made it was found that the inclined shaft placed under collapsed rocks presented stability of it`s excavation in contrast with other inclined shafts placed under intact rocks protected by safety pillars. The cause of this phenomenon is based on the fact that the intact rocks need time for the rock pressure to decrease as the primary state of tension is disturbed during extraction.

3. INVESTIGATION OF THE DEFORMATION MECHANISM FOR THE HEADING GALLERY FROM THE MINING PANEL NUMBER 5, LAYER 3 OF EXTRACTION

The heading gallery from layer 3 of coal extraction, mining panel number 5 was also investigated and the following conclusions were taken:

- in the first year of measurements the heading gallery presented stability so the convergence of the mining support varied between *4%* to *12%*;

- after exactly a year of measurements when the gallery come under the extraction front that manifest it`s influence on a distance of *0* to *14 m*, the usable section decreased with *10%* in the limits of the influence from the extraction front above and the usable section decreased with $4\ m^2$, respectivly *34%* at the intersection with the extraction front;

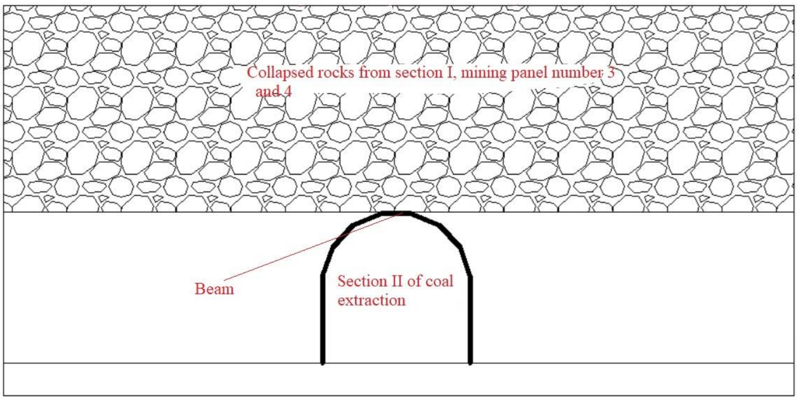

Figure 4. Place of the inclined shaft used for ventilation in the extraction front from mining panel number 5

- the decreasing of the usable section was generated by the rock pressure from the ceiling and the side wall limited by the massif of coal as it is ilustrated in Figure 5;
- as a result of the rock pressure that was concentrated to the floor of the heading gallery, the metallic profiles of the mining support recorded deformations in the same direction as the pressure. The metallic profiles of the mining support recorded a curve inside the usable section on a distance of *200mm to 400 mm* and at the ceiling the metallic profiles of the mining support moved in the direction of the collapsed rocks;
- because of the cracks developed in the coal wall and because of the existence of the other wall made of collapsed rocks in course of subsidence, the pressure manifest itself by pushing the metallic profiles from the mining support inside the usable section;
- outside the extraction front influence the heading gallery have a good stability and the convergence recorded had a maximum value of *20%* from the usable section.

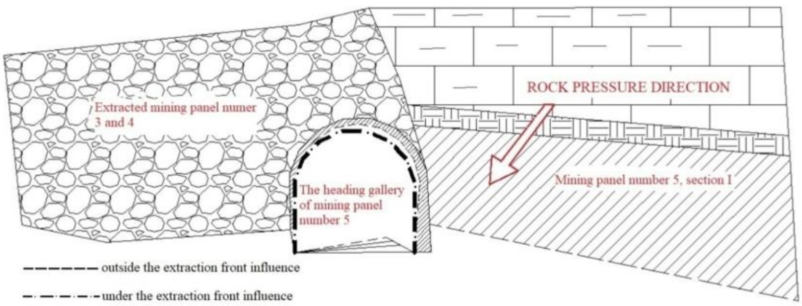

Figure 5. The convergence of the heading gallery placed near the coal massif

The solution needed to be adopted for the heading gallery from the layer 3 of extraction, mining panel number 5 in order to stop the deformations of the metallic profiles and the decreasing of the usable section is to place the gallery in the collapsed rocks at a distance of *1,0* to *1,5 m* away from the coal wall. By this action the effect of rock pressure is removed. This situation is illustrated in Figure 6.

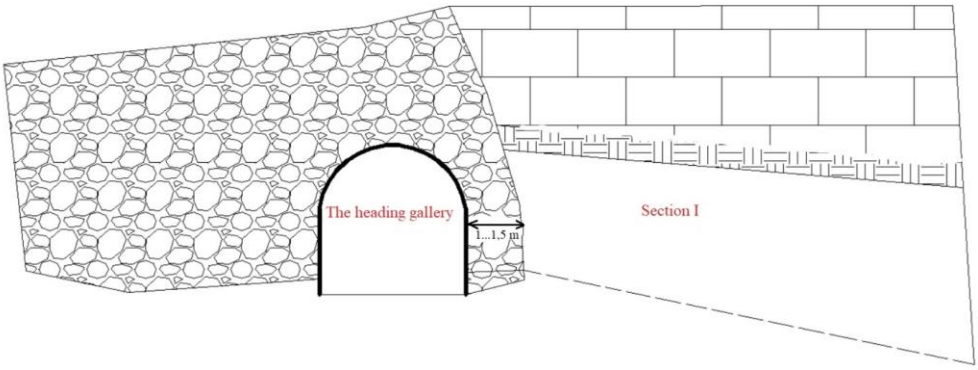

Figure 6. The heading gallery placed at a distance of *1,0* to *1,5* m from the coal massif

CONCLUSIONS

As it is described above the mining works influence each other because of their density and position in the extraction block structure but also because of a series of geotechnical factors. The deformations mechanism of the inclined shaft and the main galleries from the horizon 300 placed under the inclined shaft used for coal collecting was generated by a series of geotechnical factors like:

- the low strength of the surrounding rocks that did not exceed *8 MPa* to *10 MPa* and which suffered a permanent process of deformation and movement;
- the destructive action of the safety pillar from the inclined shaft from layer 5 of coal extraction that generated a permanent pressure on the inclined shaft from layer 3 of coal extraction;
- the concentration of a high number of mining galleries in a vertical plan;
- the convergences recorded show the fact that the galleries influenced each other and because of this the rock pressure value increased around the excavations.

In order to stop the deformation of the mining support at the connection with the heading gallery and with the main gallery, a new solution of mining support was adopted. The new solution adopted consist in double the metallic profiles and by this the carrying capacity increase from *15 tons* to *24 tons* and these values were obtained from the University of Petroșani laboratory.

The solution needed to be adopted for the heading gallery from the layer 3 of extraction, mining panel number 5 in order to stop the deformations of the metallic profiles and the decreasing of the usable section is to place the gallery in the collapsed rocks at a distance of *1,0* to *1,5 m* away from the coal wall.

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AN OVERVIEW ON THE STABILITY CONDITIONS IN JILȚ NORTH OPEN PIT (OLTENIA MINING BASIN, ROMANIA)

Florin FAUR[1], Daniel MOISUC-HOJDA[2]

Abstract: *Regardless of the period for which the lignite open pits in the Oltenia mining basin (Romania) will continue to be in operation, ensuring the stability conditions is an imperative, both in terms of workplace security, but also for the safety of the natural and anthropogenic objectives located on neighboring lands, in the so-called area of influence. In this paper, a synthesis of the research carried out in the last three years regarding the stability of the mining works in the Jilț North mining perimeter (open pit) is presented. In this sense, the results of the stability analyzes performed for normal conditions, but also under the assumption of the presence of seismic loads (taking into account the seismic episode from the beginning of 2023) are presented, and, finally, some relatively simple and low-cost solutions are suggested, that aim to increase the stability reserve and, implicitly, prevent the triggering of landslides on the working and/or dumping steps of the open pit.*

Key words: *earthquake, Jilț North, open pit, stability, waste dump*

1 INTRODUCTION

Slope stability is one of the most important issues which must be solved throughout the lifetime of any open pit or quarry. In the particular case of lignite open pits, which usually operate in soft rocks, there is a high probability for slop sliding to occur [1].

The failure and sliding of slopes in an open pit can be triggered by multiple factors, among: poorly designed geometric elements, insufficient knowledge of the geology and hydrogeology of the lignite deposit, presence of uninvestigated failure plans (faults), external factors (overloads, seismic loads, precipitations), etc. [2–14].

Among the consequences of landslides produced over time in lignite open pits are: the total or partial damage of machinery, mostly bucket wheel excavators (BWEs) (Figure 1) [15–17], the degradation or destruction of the nearby habitats involved in the sliding process, the blocking of water courses, the destruction of communication routes, or even the death of people operating the machines or who live in nearby area [1].

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Figure 1. The total destruction of a type SRs 1400 – 30/7 BWE (Alunu open pit, Berbești mining basin, Romania) [1, 17]

As previous studies highlighted, slope failure may affect either the working steps of the open pits or the slopes of the internal or external dumps all over the world. These landslides are described by the literature in terms of favoring or triggering factors and causes, unfolding mechanisms, amount or extent of the damage caused and possible prevention and mitigation measures [18–25].

One of the most frequent triggering factors of landslides is represented by seismic activity (earthquakes).

Earthquakes, of tectonic origin or generated by the displacement of earth masses along the path of existing faults, significantly influence the stability of a slope (reducing the stability reserve), often causing it to pass from an equilibrium state into an unstable one [26].

During an earthquake, vertical and horizontal forces appear and act on the slopes, which may trigger landslides that usually involve large volumes of rock. Vertical forces reduce the effective normal pressure on sliding surfaces, while much stronger horizontal forces play a decisive role in slope stability. Moreover, because during an earthquake the seismic action can have any direction, as a rule, in calculations the horizontal component is considered, this being the most unfavorable case in terms of the effect on the stability of the slopes [3, 4, 7, 26].

Such cases of earthquake-induced landslides affecting open pits are well inventoried, documented and described by the literature [27–31].

Even though the triggering factors of major slope slides can often be technically detected, their actual prediction and mitigation remain a major challenge (for practicians, researchers and academics) [1].

The main target of a stability study is to evaluate the safety factor (coefficient) or to verify the stability reserve of a slope and, on this basis, to mitigate the geotechnical risks that may occur by identifying and implementing the appropriate stabilization measures [1, 3, 5, 13, 14].

In the present study, the researches focused on aspects related to the geometry of the working fronts and internal dump designed for the development of the Jilț North open pit (in a hilly area). More precisely, the paper presents stability analyses under normal (static) conditions but also under seismic conditions, taking into account the maximum seismic acceleration for the location area. In the end of the paper some technical solutions are proposed that allow the continuation of the extractive activity under safe conditions.

2 GENERAL DESCRIPTION OF JILȚ NORTH MINING PERIMETER

2.1 Location

Jilţ mining basin (consisting of two open pits: Jilţ North and South) is located in the southwestern part of Gorj county, on the territory of Matăsari, Dragoteşti, Slivileşti and Negomir communes. It stretches between the villages of Brădețel, to the north, Ştiucani, Miculesti and Slivileşti, to the west, Corobai and Strâmtu to the south and Negomir and Timișeni to the east. Figure 2 shows the layout of the Jilț North mining perimeter [32].

Figure 2. Location of Jilț North open pit [1, 34].

Access to the area is achieved through [1]:

- Filiaşi – Turceni – Dragoteşti – Mătăsari railway;

- County road DJ 673 Turceni – Dragotești – Strâmba – Vulcan, connected to DN 66 Craiova – Târgu Jiu, which ensures access from the south;

- The modernized county road Pieptani – Strâmba – Mătăsari, connected to DN 67 Târgu Jiu – Motru – Drobeta-Turnu Severin, which provides access to the north and west.

The connection between the various settlements in the area is made by communal roads, asphalted or cobbled.

From a geomorphologic point of view, the area is characterized by a massive relief, with hills oriented approximately west – east, which structurally belongs to the Getic piedmont, which makes the transition between the subcarpathian area and the plain area.

2.2 Geology and stratigraphy of the region

The geological formations in the area of the Oltenia mining basin were formed within a process of sedimentogenesis that began in the Paleogene and ended in the Upper Pliocene, within the Getic Depression tectono-genetic unit. Functioning as a sedimentation basin, the deposits in the region are mainly made up of sandstones, conglomerates, sands and gravels, which host the lignite layers. The foundation of the Getic Depression consists of crystalline schists with granitic inclusions and a cover of Mesozoic sedimentary formations [26].

The stratigraphy of the region, highlighted by exploratory research, presents a complete sequence of sedimentary formations starting from the Paleogene and ending with the Upper Pliocene, over which the Quaternary deposits are disposed (Table 1).

Table 1. Sedimentary formations in the Oltenia mining basin [26]

PERIOD	EPOCH			DESCRIPTION
QUATERNARY	Holocene			recent alluvium of the valleys, proluvial and colluvial deposits, gravels
	Pleistocene			sands and gravels with intercalations of clays, sandy clays, clayey sands, thin layers of lignite (Lower Pleistocene), sands and gravels of the high, middle and lower terraces
PLIOCENE	Romanian	Superior		sands and gravel in which the XIV – XVII lignite strata are intercalated
		Inferior		clays and fine sands in which the VIII – XIII lignite strata are intercalated
	Dacian	Superior		alternation of clays with gray and green sandy clays, with sands and gray clayey sands in which lignite layers V-VII are interspersed
		Inferior	Superior	clays, sandy clays, sandy marls and the I – IV lignite strata horizon
			Inferior	sands with gravel intercalations and the D, C, B, A lignite strata horizon
	Pontian	Superior		sands and sandy clays with micaceous sandstones intercalations
		Median		clays and sandy clays
		Inferior		marls and clays
	Meotian	Superior		marls, clays and sandy clays
		Inferior		gravel, sands, conglomerates and clays
PALEOGENE				-

Geologically, the deposits in Oltenia belong to the Pliocene formations (Dacian and Romanian) and are made up of 21 layers of lignite, with variable extents, separated by sterile rocks (soft, cohesive and non-cohesive rocks, predominantly clays and sandy rocks) [1].

The thickness of the lignite layers varies from a few centimeters to several meters, appearing in a compact form or in the form of several coal banks, which make up the complex of a layer [26].

2.3 Tectonics of the Jilț mining perimeter

In the case of the Jilț mining sub-basin, the analysis carried out highlights that the exploitation area of the lignite deposit is part of the Getic Depression. Its constitutive formations are of Cretaceous, Paleogene, Neogene (Pliocene) and Quaternary age, within which the Dacian, Romanian and Pleistocene type deposits are the formations bearing lignite layers [32].

The tectonics of Neogene deposits is represented by both folds and faults, which correspond to deep structures and usually channel the river valleys. In the investigated area, namely the area with mining activity, the presence of the Baia de Aramă–Runcurelu–Plopşoru fault can be noted, which broadly follows the routes of the Jilţul Mare River and the Runcurelu stream. This fault separates the sector Dragoteşti–Mătăsari from the sector Tehomir–Cojmăneşti–Dealul Arşiţei [26].

3 MINING ACTIVITIES IN THE JILȚ NORTH OPEN PIT

Extraction of lignite in the Jilț North perimeter began in 1980, through two micro-open pits located in the Cerchez I and II hills, and excavations with bucketwheel excavators (BWEs) began in 1984 (when the E07 BWE, type SRs 1400 – 30/7, was put into operation).

At present, the Jilț North open pit (Figure 3), with a licensed capacity of 4.5 million t/year, supplies lignite for the Turceni Central Power Plant, a component unit of the Oltenia Energy Complex [34].

Excavation is carried out exclusively with high-capacity BWEs, type SRs 1400 – 30.

The transport of both the waste rocks and the lignite resulting from the excavations is carried out on conveyor belts. The waste rocks are transported to the internal dump (occasionally to the external one), and the lignite to the Jilţ coal depot and from here to the Turceni Central Power Plant.

The waste rocks and coal are separated by means of the distribution lanes located in the nodes.

Dumping of the waste rocks from the excavation fronts is carried out by means of spreaders (dumping machines).

Coal storage is carried out in the Jilţ depot by means of combined (depositing – extraction) and stacking machines.

Figure 3. Working fronts of Jilț North open pit (left) and the internal waste dump (right) [34]

The specific technological flux existing in Jilţ North open pit is presented in Figure 4, with the specification that the A02 spreader, which deposits sterile rocks in an exterior waste dump, is used only in emergency situations (if failure occurs to the conveyor system or the spreaders operating in the internal waste dump) [1, 43].

Currently, the Jilţ North open pit is equipped with the following high-capacity technological equipments [34]: BWEs: 6 x SRs 1400 – 30/7 (E06; E07; E14; E17; E18; E19); BWEs: 3 x SRs 470 – 15/3.5 (E09; E11; E16) – removed from the technological flux (in conservation, near the premises of the administrative building and the coal depot); High-capacity conveyor belts, types: B1400; B1600; B1800; B2000; B2250, over 30 km; Belt wagons; Spreaders: 3 x A2RsB 6500.90 (A01, A03, A05) and one A2RsB 6500.60 (A02); Depositing machines: combined machine type KsS 5600×40 and stacking machine type ASG 6000.

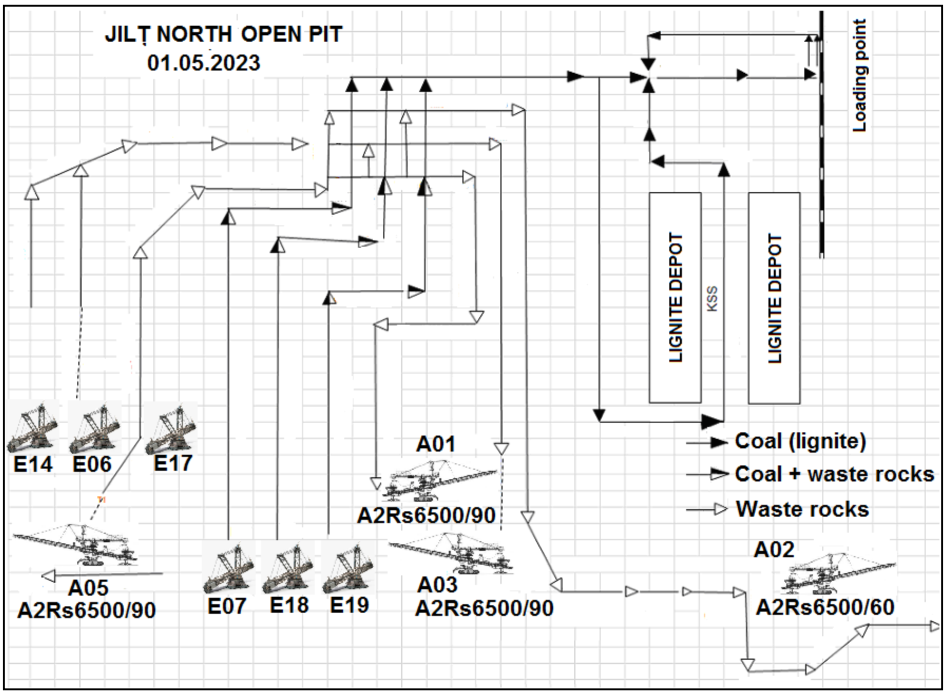


Figure 4. Technological flux existing in Jilț North open pit [1]

Added to these are a variable number (being used jointly with the Jilț South open pit) of classic excavators (with wheels and tracks), dumping trucks and bulldozers, used for related activities (profiling, access roads, leveling, etc.) [1, 34].

In Jilţ North open pit, the exploitation method used is the one with the transshipment of a part and the transport of another part of the sterile rocks to internal dumps (Figure 5) and the technology of excavation, transport and dumping in continuous flux, through the use of excavation, transport and dumping/deposition complexes. The material deposited in the waste dump is leveled with the help of different types of bulldozers [34].

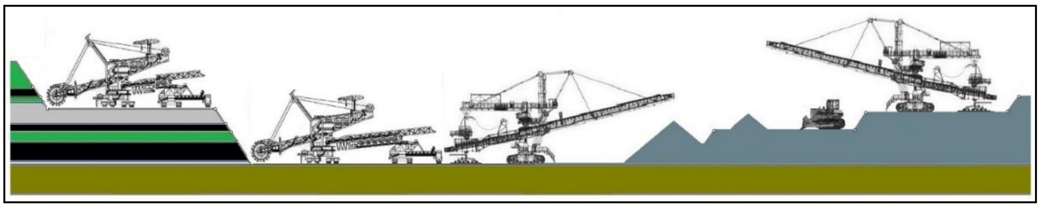


Figure 5. Exploitation method applied in Jilț North open pit [1, 34]

It is expected that the current exploitation method and technological flux will be maintained until the cessation of productive activities (2028 according to the current license, or, by its extension, 2035 at most) [1].

4. STABILITY ANALYSES FOR NORMAL (STATIC) CONDITIONS

4.1. Modeling the analysis sections

In order to be able to model the stability analysis sections of the working fronts of the Jilț North open pit and of the dumping fronts of the inner dump, several stages were completed.

The first consisted of drawing the calculation section on the situation plan provided by the mining operator. Thus, through the central area of the mining perimeter, a cross section was drawn, which intersects both the working fronts of the open pit and the deposition fronts of waste rocks in the internal dump. This section was then divided in 2 separate sections: A - A for the working fronts (Figure 6) and B - B for the waste dump (Figure 7).

Then, based on the coordinates for the initial cross section, taking into account the stratigraphy of the deposit, and the information from the written documentation [35], the sections from the end of 2023 and the calculation model were created using the Slide software, having the same order of scale horizontally and vertically.

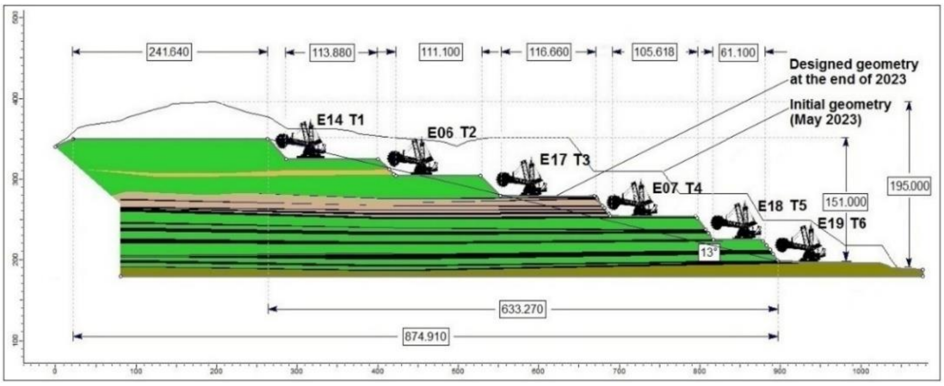


Figure 6. Cross section A – A (geometry at the end of 2023) of the working fronts [1]

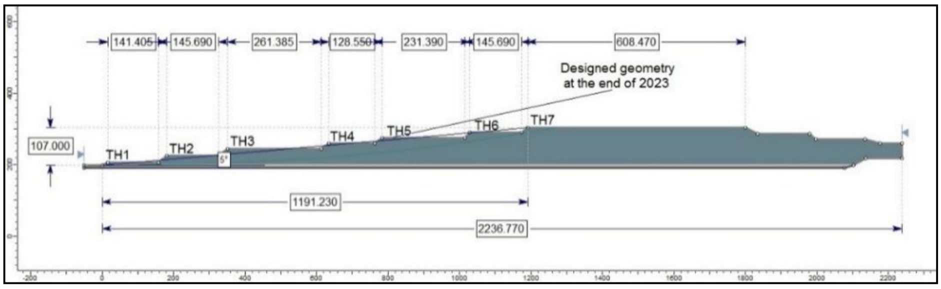


Figure 7. Cross section B – B (geometry at the end of 2023) of the dumping fronts [26]

With the help of the measuring tools within the Slide software, the geometric elements of the working and dumping fronts were determined on the created models, for the existing at the end of 2023, presented in Table 2.

Table 2. Geometry of the working and dumping fronts (cross sections A – A and B – B) [26]

Geometric Element	**Open Pit**
Development of the working fronts (cross section) (m)	633.27
Height of the general slope (m)	153.41
Number of steps	6
General slope angle (°)	13
Height of the steps (m)	20.00–30.00
Berms width (m)	61.10–116.66 *
Slope angle of individual steps (°)	42–53
Geometric element	**Internal waste dump**
Development of the dumping fronts (cross section) (m)	1191.23
Height of the general slope (m)	107
Number of steps	7
General slope angle (°)	5
Height of the steps (m)	9–20
Berms width (m)	141.40–261.38 **
Slope angle of individual steps (°)	28–49

* Except for the upper berm of the T1 step; ** Except for the upper platform.

4.2. Selection of physical-mechanical characteristics

In order to determine the physical and mechanical characteristics necessary in the stability analyses, a number of 10 samples (of approx. 30 kg each) were collected (5 from the working steps and 5 from the interior waste dump), according to the standards [36–38], both from the areas where landslides occurred in the last 5 years, as well as from the rest of the working and dumping fronts, later to be analyzed in the specialized laboratories.

The samples were then divided in 2 equal parts, packed in plastic bags (to maintain the natural moisture) and transported to the two laboratories (Earth Mechanics Laboratory of the University of Petroșani – approx. 1.5 h drive and the GeoLogic Laboratory in Calan - approx. 2.5 h drive).

The samples collected from the working fronts of the Jilț North open pit were subjected to laboratory tests, and a series of physical and mechanical characteristics were determined, according to specific standards [36–38]: moisture, particle size (granulometry), specific and volumetric weight, porosity, pore index, plasticity limits, consistency indexes, cohesion and angle of internal friction (shear strength), oedometric tests, etc.

Based on the statistical processing of the values determined in the two laboratories and data retrieved from the documentations [35], the values presented in Table 3 were selected, and further used in the stability analyses.

Table 3. Values of the physical-mechanical characteristics considered in the stability analyses for Jilț North perimeter [26]

The Nature of Rocks from the Analysis Sections		γ_{vnat} [kN/m^3]	c_{nat} [kN/m^2]	φ_{nat} [°]
	Sandy clays (steps T1–T3)	22.00	25.00	20.00
	Clayey sands (intercalation in step T2)	21.00	15.00	16.00
	Coal clay (on top of layer X, between the banks of layer X, layers X and XII and as discontinuity of layer XII)	18.00	33.25	28.00
	Lignite (layers V–X and XII)	13.40	200.00	35.00
	Compact clay (on top of the pressurized aquifer, direct foundation of the internal waste dump)	19.00	52.00	30.00
	Mixture of waste rocks	18.50	20.75	21.00

γ_{vnat}, c_{nat}, φ_{nat}—Volumetric weight, cohesion and angle of internal friction (at natural moisture)

4.3. Results of the stability analyses

4.3.1 Stability of the working fronts

For the present study, the stability analyses were performed using methods based on the limit equilibrium theory (Fellenius, Bishop and Simplified Janbu), as they offer credible and satisfactory results [1, 26].

These methods, based on limit equilibrium theory, are the commonly used methods (in engineering practice) for determining the safety factor of a slope, as they proved their reliability and are easy to understand by mining operators [39]. Most of them assume that the sliding surface is a circular one, and the applied computing algorithms are based on this assumption [1–5, 7–10, 17, 26].

The stability analyses were performed using a specialized software for geotechnical studies (Slide). This software analyses the stability of natural and artificial slopes of any geometry, both under static and seismic conditions, as well as in the presence of water (hydrostatic and/or hydrodynamic conditions, submerged slopes) [40].

The program automatically calculates the stability coefficients, using several methods based on the limit equilibrium theory. According to this theory, the sliding mass is divided into vertical strips and the stability of the slope is analyzed in the hypotheses of a limit equilibrium between active and passive forces [40].

The results of the stability analyzes performed for the individual slopes, as well as for different step systems, are presented in Table 4, respectively Figures 8 and 9.

Table 4. Results of the stability analyses for the working fronts (at the end of 2023) [1]

Section	Step no.	Height H, [m]	Slope angle α, [°]	Stability factor (coefficient) Fs			Observations on the transmission mode of the potential sliding surfaces
				Fellenius	Bishop	Janbu	
A - A	T1	25	48	0.890	0.911	**0.884**	The minimum surfaces materialize along the entire height of the slope, intersecting the upper berm, some passing through the tip of the slope and some trough the base (fig. 8)
	T2	20	42	1.300	1.408	**1.274**	The minimum surfaces materialize along the entire height of the slope, intersecting the upper berm, passing through the base of the slope
	T3	25	52	0.952	0.959	**0.947**	One of the minimum surfaces traverses the entire height of the slope, intersecting the upper berm at 5 m from its edge, and passes through the tip of the slope (fig. 9)
				1.355	1.422	**1.341**	Most of the minimum surfaces materialize along the entire height of the slope, intersecting the upper berm, passing through the base of the slope
	T4	25	52	**2.095**	2.454	2.276	The minimum surfaces materialize along the entire height of the slope, intersecting the upper berm, passing through the base of the slope
	T5	30	53	1.236	1.232	**1.157**	The minimum surfaces materialize on a part of the slope, intersect the upper berm and pass through the roof of lignite layer VIII
	T6	26	53	1.354	1.374	**1.313**	The minimum surfaces materialize on a part of the slope, intersect the upper berm and pass through the roof of lignite layer V

	Step systems	Fellenius	Bishop	Janbu	Observations on the transmission mode of the potential sliding surface
	T1 – T2	2.559	2.754	**2.460**	Intersects the sandy clays and clayey sands layers in the overburden
	T2 – T3	3.516	3.665	**3.430**	Passes through the base of step T3, partly through the X lignite layer and coal clays
	T3 – T4	3.687	4.028	**3.458**	Passes through the base of step T4, intersecting lignite layers VIII - X and coal clays
	T4 – T5	3.732	3.795	**3.598**	Passes through the slope of step T5, intersecting lignite layers VII - X and coal clays
	T4 – T6	2.579	2.703	**2.552**	Passes through the slope of step T6, intersecting lignite layers VI - X and coal clays
	T5 – T6	1.995	2.059	**1.947**	Passes through the slope of step T6 and through the roof of the lignite layer V
	General slope (all steps)	**Fellenius**	**Bishop**	**Janbu**	**Observations on the transmission mode of the potential sliding surface**
	T1 – T6	2.726	2.761	**2.702**	Passes through the slope of step T6 and through the roof of the lignite layer V

minimum surfaces – the first 10 potential sliding surfaces with the lowest values of the stability factor

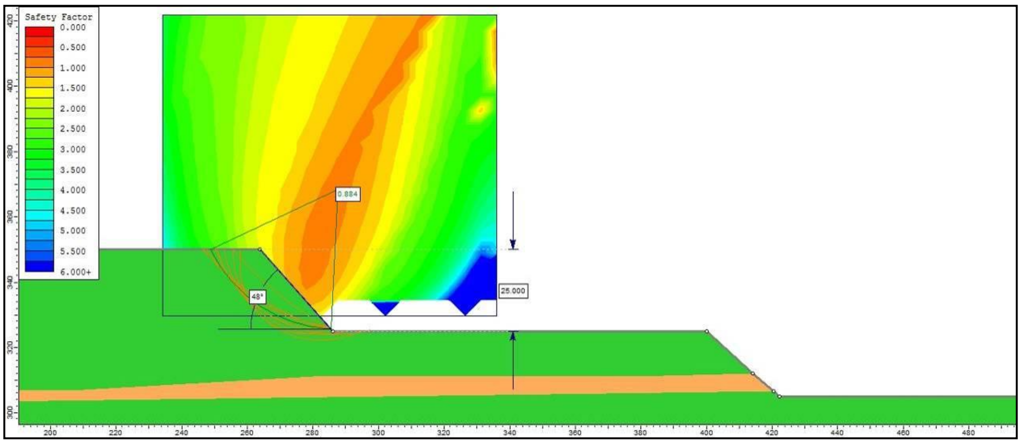


Figure 8. Stability analysis for T1 step (h = 25 m, α = 48°) [1]

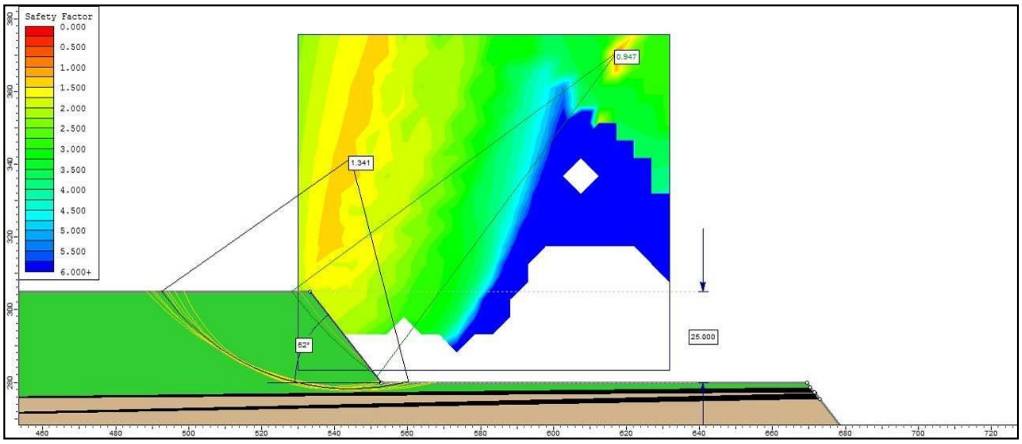


Figure 9. Stability analysis for T3 step (h = 25 m, α = 52°) [1]

As a result of carrying out the stability analyzes for the designed situation, the following conclusions can be drawn [1]:

- The stability analyzes in this paragraph were carried out for the designed conditions, the geometry considered for the analysis section to be achieved at the end of 2023, and took into account the stratigraphic columns received from the Jilț North open pit;
- For most situations, the lowest values of the stability factor were determined by Janbu's method;
- For the T1 step, the stability analyzes highlighted a sub-unit value of the stability factor, i.e. a slope below the equilibrium limit. The main reasons are represented by the relatively unfavorable geometrical elements (height of 25 m and inclination of 48°), but also by the physical-mechanical characteristics of the rocks in the structure of the slope. In order to solve the problem of the stability of this step, a reshaping of the initially designed geometric elements is necessary, by using a scientific method, which guarantees the continuation of extractive activities in safe conditions;
- In the case of T3 step, following the performance of stability analyses, it was found that there is the possibility of materializing a critical sliding surface, which starts from approx. 5 m away from the edge of the upper berm and passes close to the tip of the slope. Such a slide, although superficial, can cause interruptions in the productive activity and implicitly economic losses. To prevent such a situation, a reshaping of the geometric elements is also recommended;
- For the rest of the situations analyzed (the rest of the individual slopes, different systems of steps and the general slope), the values of the stability factor indicate a satisfactory reserve, in accordance with the national technical prescriptions [41] and the recommendations from the specialized literature [2–5, 7–10, 17] (in general, they recommend a minimum stability reserve between 10 – 15% for working slopes – with a reduced duration of staying in place);
- In the case of the steps whose structure also includes lignite layers (T4 – T6), although they have more unfavorable geometrical elements (theoretically) than the steps excavated in waste rocks (T1 – T3), due to the superior physical and mechanical

characteristics of lignite (especially the shear strength), the values of the stability factor (coefficient) are satisfactory (stability reserves above 15%).

4.3.2 Stability of the dumping fronts

In the particular case of the Jilț North internal dump, deposition is carried out using types A2RsB 6500.90 (A01, which works in tandem with the E19 excavator located on the base of the open pit, A03, A05) and A2RsB 6500.60 (A02) spreaders. At the present, the geometry of individual slopes is variable, influenced by the rate of excavation and the type of excavated material, as well as how the waste dump is constructed with the help of spreaders (formation of deposition cones, which are later leveled with bulldozers) (Figures 4 and 5).

We mention that no stability analyzes were performed for the slopes on the right side of the cross section (Figure 7). These slopes, according to observations from the field, are completely covered by vegetation, spontaneously installed grasses, and trees (acacias) planted as part of the ecological reconstruction works carried out so far in this mining perimeter. No active landslides or phenomena leading to landslides (tension cracks, erosions, abnormal settlements, etc.) were observed.

The results of the stability analyzes performed for the individual slopes, as well as for different step systems, are presented in Table 5, respectively Figures 10 and 11.

Table 5. Results of stability analyzes for the dumping fronts [33]

Section	**Individual step**	**Height H, [m]**	**Slope angle α, [°]**	**Stability factor (coefficient) Fs**			**Observations on the transmission mode of the potential sliding surface**
				Fellenius	**Bishop**	**Janbu**	
B - B	TH1	9	28	2.181	2.215	**2.159**	Minimum surfaces materialize along the entire length of the slope, without passing through the base (roof of the pressurized aquifer below lignite layer no. V)
	TH2	18	40	1.149	1.224	**1.133**	Part of the minimum surfaces pass through the base of the slope, step T1 (fig. 10)
	TH3	20	38	1.393	1.532	**1.382**	All minimum surfaces pass through the base of the slope
	TH4	15	35	**2.615**	3.086	2.632	All minimum surfaces pass through the base of the slope, through the body of the lower step, T3
	TH5	15	35	**3.077**	3.702	3.113	All minimum surfaces pass through the base of the slope, through the body of the lower step, T4
	TH6	15	49	**3.741**	4.664	3.861	All minimum surfaces pass through the base of the slope, through the body of the lower step, T5
	TH7	15	41	**3.707**	4.594	3.793	All minimum surfaces pass through the base of the slope, through the body of the lower step, T6
	Step system			**Fellenius**	**Bishop**	**Janbu**	**Observations on the transmission mode of the potential sliding surface**
	TH2 – TH3			5.032	5.230	**4.907**	The potential sliding surface passes through the slope of step T2 (Fig. 11)

	TH3 – TH4	> 7	> 7	**> 7**	The potential sliding surface passes through the tip of the slope of step T3 (Fig. 11)
	TH4 – TH5	4.402	4.602	**4.305**	The potential sliding surface passes through the base of the slope of step T4 (Fig. 11)
	TH5 – TH6	> 7	> 7	**> 7**	The potential sliding surface passes through the slope of step T5 (Fig. 11)
	TH6 – TH7	4.279	4.568	**4.216**	The potential sliding surface passes through the base of the slope of step T6 (Fig. 11)
	TH4 – TH6	5.596	5.816	**5.557**	The potential sliding surface passes through the base of the slope of step T4 (Fig. 11)
	TH4 – TH7	> 7	> 7	**> 6**	The potential sliding surface passes through the slope of step T4 (Fig. 11)
	General slope	**Fellenius**	**Bishop**	**Janbu**	**Observations on the transmission mode of the potential sliding surface**
	TH1 – TH7	5.516	5.526	**5.515**	The potential sliding surface passes through the slope of step T1

minimum surfaces – the first 10 potential sliding surfaces with the lowest values of the stability factor

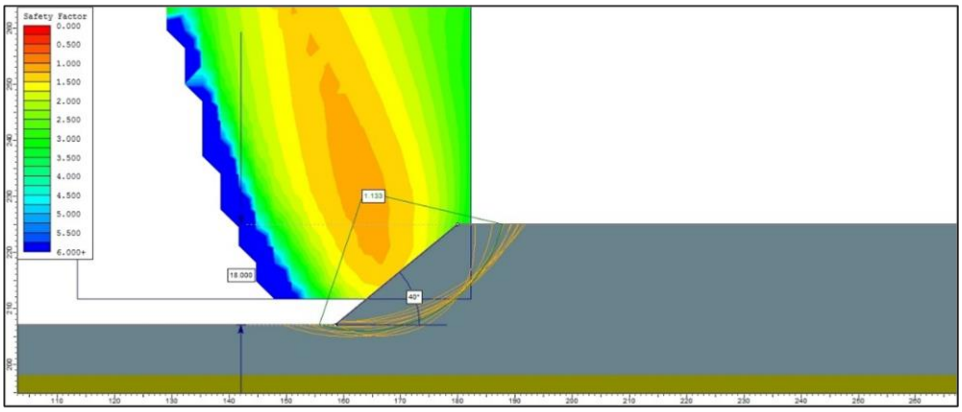


Figure 10. Stability analysis for TH2 step (h = 18 m, α = 40°) [33]

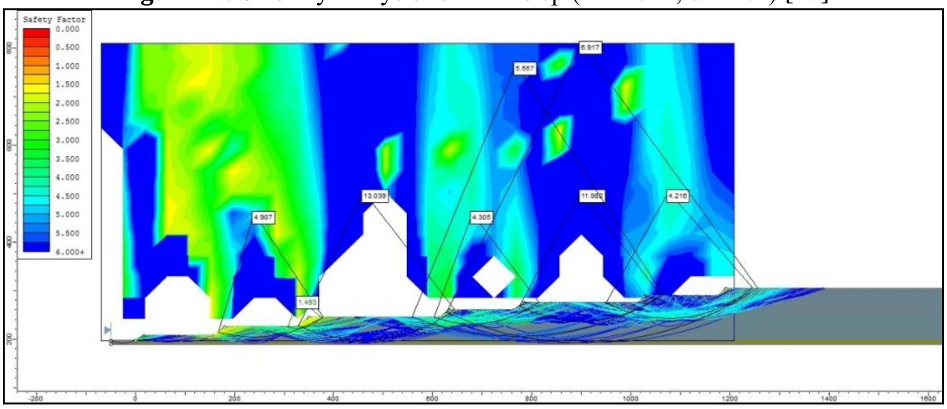


Figure 11. Stability analyzes for different step systems [33]

As a result of carrying out stability analyzes for the Jilţ North internal waste dump in the designed situation, the following conclusions can be drawn [33]:

- The stability analyzes within this paragraph were carried out for the designed conditions, the geometry considered for the analysis sections is to be achieved the end of 2023, according to the documentation received from the U.M.C. Jilț;
- For most situations, the lowest values of the stability factor were determined by Janbu's method. The exceptions to this rule are represented by steps TH4 – TH7, for which the lowest value of the stability factor was obtained by Fellenius' method;
- There is only one situation for which, although the value of the stability factor is above unit (1), there are values below 1.3, recommended by the specialized literature [2–5, 7–10, 17, 41] for definitive slopes or with a long duration of staying in place. This situation is recorded for the TH2 step (Fs = 1.133). To increase the stability reserve, it is recommended to reduce the slope angle from 40° to 35°.
- If the configuration of the slopes of the internal dump designed for the end of 2023 will also be the final configuration (that is, in the situation where the productive activity, and implicitly that of depositing sterile rocks, will be stopped) then, for reasons related to the ecological reconstruction of the land occupied by the Jilț North internal waste dump, a reduction of the slope angles will be required for each of the 7 steps, so that they allow the access of the machinery and personnel involved in these works;
- For the rest of the analyzed situations (the rest of the individual slopes, different systems of steps and the general slope), the values of the stability factor indicate a satisfactory reserve, in accordance with the technical prescriptions and recommendations from the specialized literature [2–5, 7–10, 17, 41].

Although the stability analyzes do not indicate values that signal an imminent danger of landslides, we must take into account that these analyzes were carried out taking into account values of the physical-mechanical characteristics determined in conditions of natural moisture of the samples collected from the field.

Thus, we must take into account the fact that under the conditions of saturation of the stored rocks, areas of plastic yielding can materialize in the body of the dump, which, in turn, can trigger landslides that can involve large volumes of material. This type of phenomena, large-scale landslides preceded by local plastic failure, are quite common in the case of waste dumps from the Oltenia mining basin. In this sense we mention the following landslides: the external dump of the Roşia de Jiu open pit (1995); the external dump Ştiucani, Jilţ South open pit (1992, 2001); the external dump Mănăstirii Valley, Lupoaia quarry open pit (2000); the external dump Negomir Valley, Pinoasa open pit (2001); the external dump Rogoazelor Valley, Rosiuța open pit (2001 – 2008); the external dump Bujorăscu Mic, Rosiuța open pit (2007); the external dump Berbești West, of the open pit with the same name (2017) etc. [33].

5. STABILITY ANALYSES FOR SEISMIC CONDITIONS

5.1. Seismic framing of the area

According to [42, 43], the area of the Jilț mining basin are characterized by a 7_1 (MSK scale) seismic intensity, and a return period of about 100 years and the peak ground acceleration is 0.15 g. The average recurrence interval (IMR) is 225 years, with an overtaking probability of 20%. The control (corner) period Tc of the response spectrum is 0.7 s.

The unusually intense seismic activity for this area in 2023 began on 13 February, with the occurrence of the 5.2 ML earthquake, turning the Oltenia area into a real epicenter of research related to the reassessment of the seismic hazard and risk.

By the time this study was carried out, over 4000 seismic movements were recorded in the area of interest, of which over 40 had magnitude ≥ 3 ML, updated after [26]:

- over 30 earthquakes with a magnitude between 3–3.9 ML;
- nine earthquakes with a magnitude between 4–4.9 ML: 4.1 ML (3.2 Mw)—14 February 2023, 4.2 ML (3.3 Mw)—16 February 2023, 4.3 ML (3.3 Mw)—17 February 2023, 4 ML (3.2 Mw)—22 February 2023, 4.9 ML (4.4 Mw) 20 March 2023, 4.2 ML (3.3 Mw)—19 June 2023, 4.2 ML (3.3 Mw)—18 July 2023; 4.5 ML (3.3 MW)—21 August 2023; 4.3 ML (3.3 Mw)—10 November 2023;
- two earthquakes with magnitude ≥5 ML: 5.2 ML (4.8 Mw)—13 February 2023 and 5.7 ML (5.4 Mw)—14 February 2023.

The seismic doublet type system recorded during this period represents the most intense activation of the area since there has been seismic monitoring in this region. The two earthquakes with magnitudes of 5.2 and 5.7 ML (as well as the one with the magnitude of 4.9 ML) were felt with intensities V–VI on the Mercalli scale in the epicentral area and produced minor and moderate damage [44].

The peak (maximum) ground acceleration recorded (PGA) for the strongest earthquake was 106.7 cm/s^2, while the maximum computed spectral acceleration (SA) was 307.1 cm/s^2, corresponding to a period of 0.23 s, on the North-South (NS) component of Gura Zlata seismic station [26, 44].

Regarding the seismic future of the Oltenia region (Gorj County in particular), according to specialists, it is premature to make assessments in this regard. However, according to statements made by the general director of National Research and Development Institute for Earth Physics [45], we can expect in the future that earthquakes with a local magnitude (ML) of 6 or even 6.5 will be recorded.

5.2 Results of the stability analyses under seismic load

The selected analysis sections for the present paragraph are those for which low values of the stability factor were obtained (but not the one below unit, as they are unstable even under static conditions – T1 and T3 from paragraph 4.3.1), considering that they are the most prone to a loss of balance if a significant seismic event occurs in the area.

Stability analyses were carried out for part of the working slopes of the open pit and the internal dump. For this stage of the study, an earthquake with a maximum ground acceleration a_g = 0.15 g was considered, in accordance with the seismic framing of the Romanian territory.

The results of these analyses for the same considered sections are presented in Table 6 and Figures 12-15. To better highlight (compare) the potential influence of an earthquake on the stability of the slopes we present the results both for static and seismic conditions.

Table 6. Stability results for Jilț North perimeter [26]

Section	Individual Step	Height H, [m]	Slope Angle α [°]	Stability Factor, Fs					
				Initial Conditions			With Seismic Load (a_g = 0.15 g)		
				Fellenius	Bishop	Janbu	Fellenius	Bishop	Janbu
Jilț North open pit slopes									
A - A	T2	20.00	42	1.300	1.408	1.274	0.938	1.000	**0.900**
	T5	30.00	53	1.236	1.232	1.157	1.039	1.017	**0.886**
Jilț North interior waste dump slopes									
B - B	TH2	18.00	40	1.149	1.224	1.113	0.886	0.929	**0.855**
	TH3	20.00	38	1.393	1.532	1.382	1.015	1.095	**0.982**

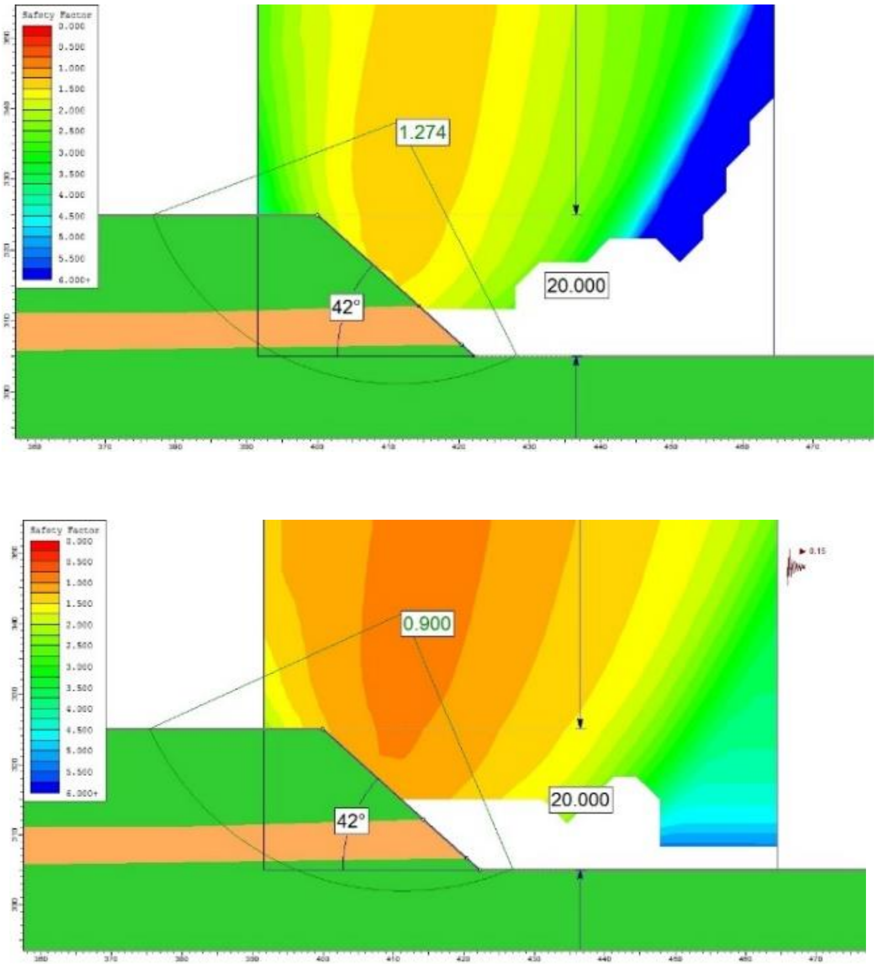


Figure 12. Results for the T2 working step. Static conditions (above); With seismic load (down) [26]

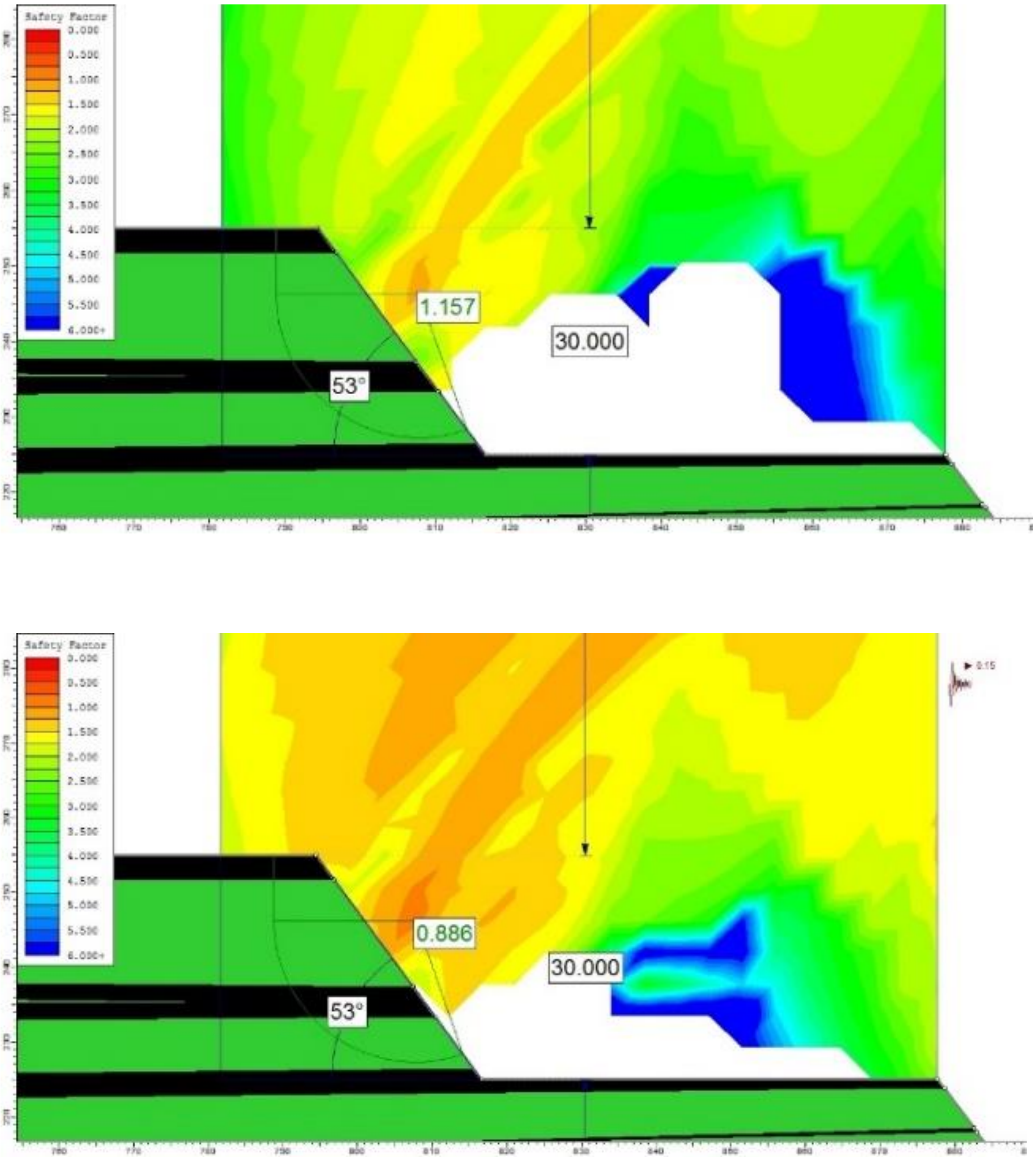


Figure 13. Results for the T5 working step. Static conditions (above); With seismic load (down) [26]

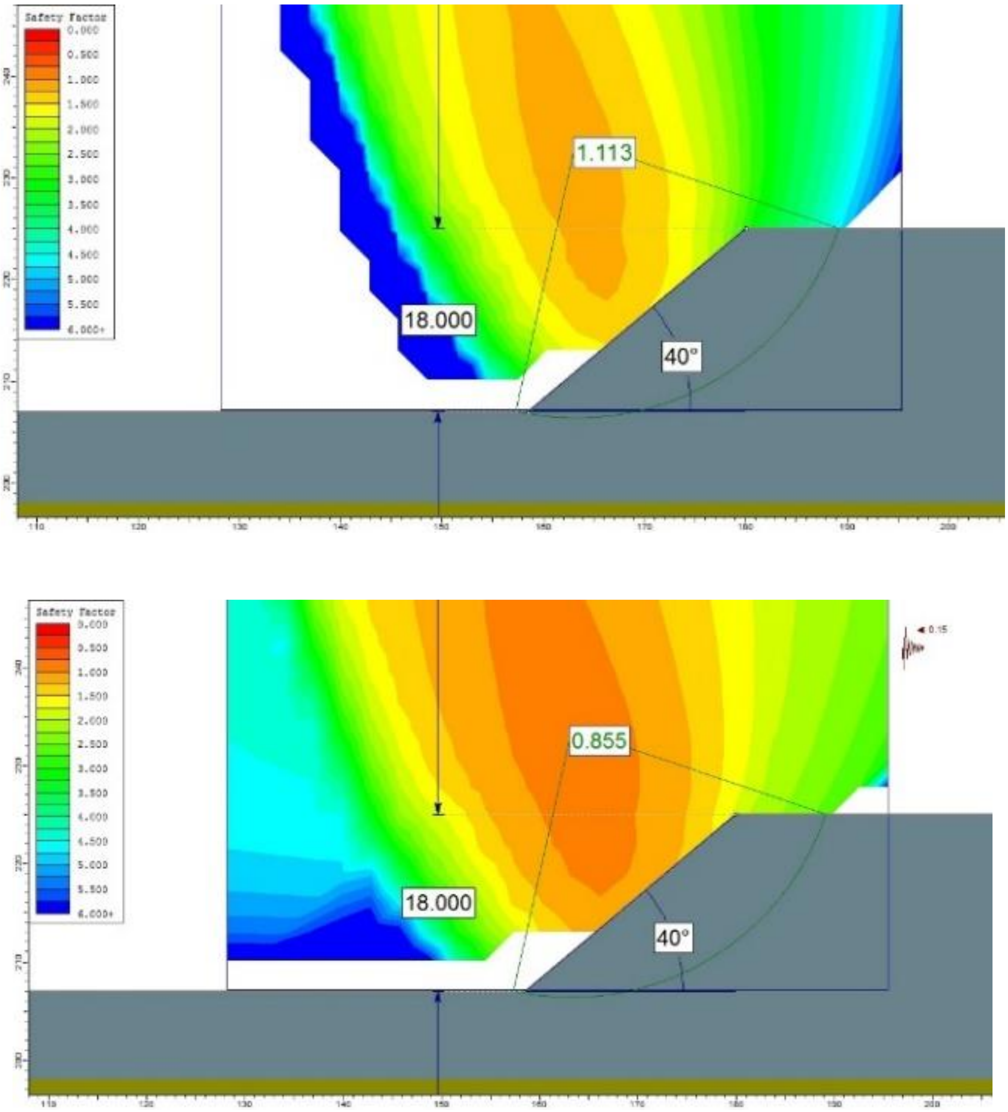
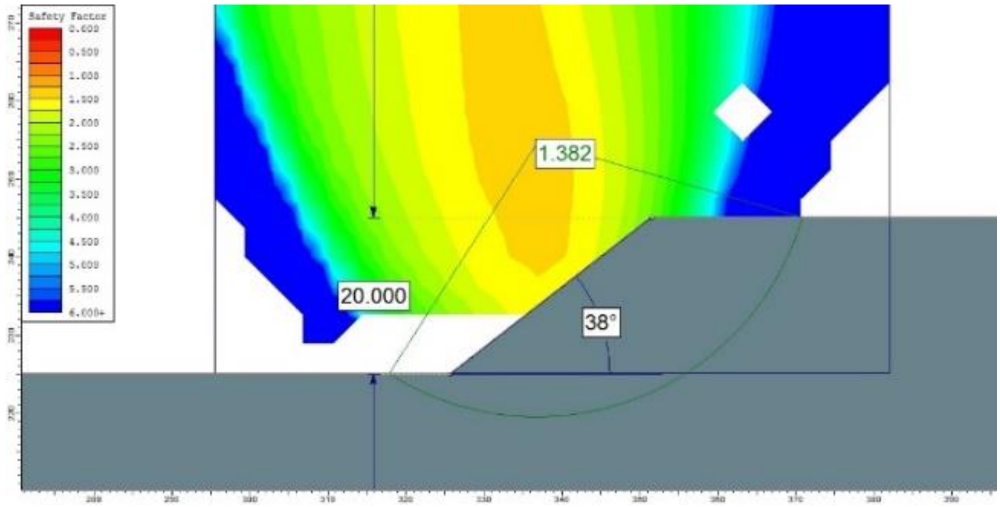


Figure 14. Results for the TH2 step of the interior dump. Static conditions (above); With seismic load (down) [26]



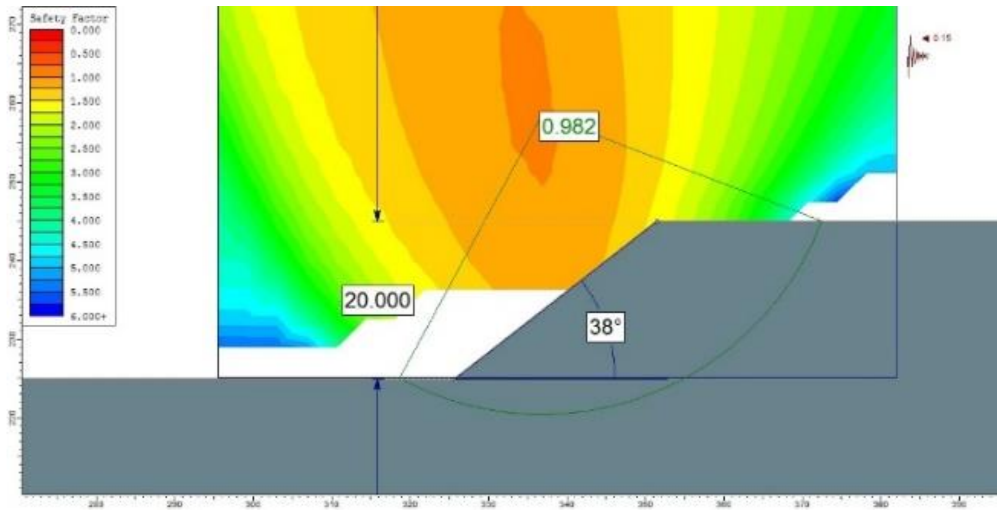


Figure 15. Results for the TH3 step of the interior dump. Static conditions (above); With seismic load (down) [26]

The lowest values of the stability factor, both for the initial situation and under the influence of a seismic load, were obtained by the Simplified Janbu method.

As can be seen from Table 5 and Figures 12–15, the values determined for the stability factor in the initial conditions are above unit, meaning that the slopes are considered to be stable. However, for three of the presented situations (T2, T5 and TH2), the minimum value of the stability factor is below that of 1.3, indicated by the specialized literature [2–5, 7–10, 17, 41] for slopes with a long duration of remaining in place, and for the fourth (TH3), the minimum value is close to this limit. These values comply with the requirements stipulated by the regulations [41] only for working slopes with a short period of staying in place.

In the conditions in which we take into account the action of a seismic load, with a ground acceleration equal to 0.15 g, for all four analyzed cases the value of the stability factor drops below 1, which indicates that they are passing into a state of imbalance (unstable slopes) [26].

6 REDESIGNING THE UNSTABLE WORKING FRONTS

6.1 Redesigning the T1 step of the open pit

To determine the stable geometry, we used the grapho-analytical procedure of Hoek-Bray [2], which (although seems to be old) proved its viability in many cases of stability analysis and design of the geometric elements of engineered slopes, being at the same time simple to use. The hypothesis on which this procedure is based is that the slopes slides occur following a circular pattern.

Starting from the factors influencing the stability of the slopes, Hoek and Bray graphically shown correlations that exist between the functions "X" (of the slope angle, α) and "Y" (of the slope height, H), depending on the geotechnical characteristics of the rocks (γ_v, c, φ) and the slope safety or stability factor (coefficient) [2].

To obtain a required values for the stability coefficient, Fs > 1.15 for the T1 step and Fs > 1.30 for T3 step of the open pit, the resizing procedure can follow either the determination of the slope angles for given heights or the determination of the maximum heights for given slope angles.

In this regard, the geometric elements were determined so as to ensure an appropriate stability reserve for the situation in which the initial designed heights are maintained.

Thus, for the given heights H - of the slopes and by knowing the geotechnical characteristics of the rocks, the function Y is calculated, and from the points of intersection of its value with the curve of the stability coefficient Fs = 1.2, respectively 1.4, the value of the function X, of the slope angle α, is obtained on the abscissa axis, from which the actual size of the slope angle α is determined.

Since for step T1 the determined value of the slope angle was significantly below 40°, difficult to achieve with the help of BWEs type SRs 1400 – 30 (under the conditions of maintaining the designed height of 25 m), we considered a technical solution by dividing it into sub-steps [1].

The construction of two sub-steps, ST1 and ST2, with a height of 5 m, berms of 15 m and a slope angle of 45°, excavated with wheeled classic excavators and transport of waste rocks with dumping trucks (discontinuous flux) and a third sub-step ST3, 15 m high, excavated with BWE E14, type SRs 1400 – 30 (currently operating on T1 step). At the same time, the slope angle for the ST3 sub-step will be reduced to 40° (Figure 16) [1].

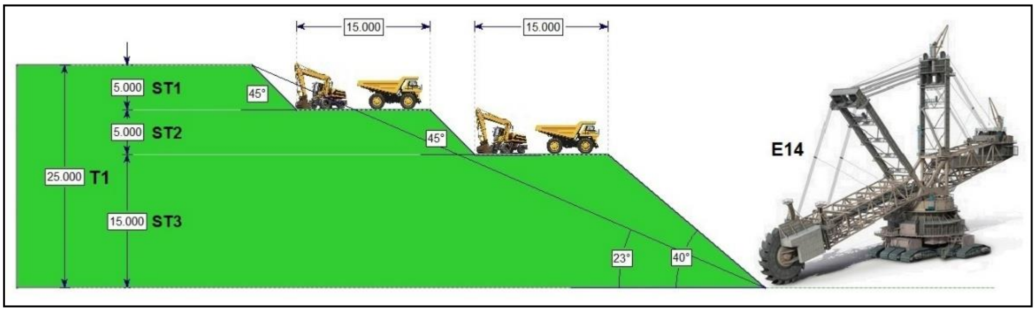


Figure 16. Technical solution proposed for step T1 (excavated in the overburden) [1]

As can be seen from figure 16, the overall slope angle of the sub-step system, into which step T1 has been divided, will be of 23°.

In this variant, even if the first two sub-steps are excavated in discontinuous flux, due to their position, at the top of the hill (meaning that the length of the excavation front and implicitly the volume of excavated rocks, are much smaller compared to the rest of the working steps) the general technological flux of the open pit will not be interrupted (the excavations can be done in parallel, using several wheeled classic excavators on each sub-step). The lower excavation capacity (compared to a BWE type SRs 470) is compensated by the increased mobility of classic excavators, whose movement in the working area will not involve stopping the activity in the open pit [1].

Then, we proceeded to verify the results obtained from the redesigning process (through the Hoek-Bray procedure). For this purpose, a new set of analyzes using the Slide software (considering the same physical-mechanical characteristics, presented in table 2) was carried out, the results being presented in Table 7.

Table 7. Results of the stability analyses for the redesigned slops (T1 step) [1]

Step no.	**Sub-step no.**	**Height H, [m]**	**Slope angle α, [°]**	**Stability factor (coefficient) Fs**			**Observations on the transmission mode of the potential sliding surface**
				Fellenius	**Bishop**	**Janbu**	
T1	ST1	5	45	2.158	2.215	**2.131**	The critical sliding surface materializes along the entire height of the slope, intersecting the upper berm of ST1 (at 3.5 m from the edge) and passing through the tip of the slope
	ST2	5	45	2.265	2.269	**2.237**	The critical sliding surface materializes along the entire height of the slope, intersecting the upper berm of ST2 (at 1 m from the edge) and passing through the tip of the slope
	ST3	15	40	1.163	1.204	**1.138**	The critical sliding surface materializes along the entire height of the slope, intersecting the upper berm of ST3 (at 4 m from the edge)

							and passing through the tip of the slope
	ST1 – ST2 – ST3 (sub-step system)	25	23	1.803	1.938	**1.751**	The critical sliding surface materializes along the entire height of the sub-step system (or T1), intersects the upper berm of ST1 (at 5 m from the edge) and passes through the slope of ST3

For all analyzed situations, the minimum values of the stability factor were obtained by Janbu's method, and the lowest value of the stability factor is obtained for the ST3 sub-step (however the value is above 1.13 – a stability reserve greater than 13%) [1].

For the sub-steps system that make up the T1 step, the value determined for the stability factor is higher (Fs = 1.751) than the one imposed (Fs = 1.2) at the time of determining the geometric elements (slope angle) by the Hoek-Bray procedure [1].

The deviation from the imposed values, for T1 step, is due to its division in sub-steps

Therefore, we can consider that the results obtained through the redesigning process are confirmed by the subsequent stability analyses, the values obtained for the stability factor being able to ensure the necessary conditions to continue the extractive activity safely.

6.2 Redesigning the T3 step of the open pit

In the case of T3 step, applying the same procedure, it turned out that in order to increase the stability reserve to the desired value (Fs > 1.30) a reduction of the slope angle from the initially designed 52° to 45° is sufficient, which is easy to achieve with the E17 BWE (type SRs 1400 – 30) currently operating on this step [1]. Table 8 presents the results for the stability analyses performed after the slope angle reduction.

Table 8. Results of the stability analyses for the redesigned slops (T3 step) [1]

Step no.	**Sub-step no.**	**Height H, [m]**	**Slope angle α, [°]**	**Stability factor (coefficient) Fs**			**Observations on the transmission mode of the potential sliding surface**
				Fellenius	**Bishop**	**Janbu**	
T3	-	25	45	1.396	1.472	**1.380**	The critical slip surface materializes over the entire height of the slope, intersecting the upper berm and passing through the base of the slope

For the T3 step, the value determined (Fs = 1.380) is slightly below the imposed one (Fs = 1.4).

The deviation from the imposed values for T3 step is due to the reading errors of the figures resulting from the interpolations on the graph (these being done classically, without the help of a computer).

6.3 Redesigning the geometry under seismic conditions

Although the analyses carried out are able to provide us with valuable data regarding the evolution of the stability reserve in the event of a significant earthquake in the studied area, the software used does not allow us to perform dynamic simulations.

The software (Slide 2D – version 6.0.2.5) only allows the introduction of a maximum value of the seismic acceleration (peak acceleration), given that an earthquake is characterized by a certain duration of action and may have several peak moments in which the acceleration has values close to the maximum.

By using methods that involve dynamic programming and which may incorporate spatial variability, time decay of the mechanical proprieties and earthquakes, both the critical sliding surface and the value of the stability factor may differ substantially from the ones obtained by classic methods (based on static mechanics) [46–78].

Moreover, software is currently being developed that can perform advanced dynamic simulations that can take into account a seismic sequence (a series of earthquakes), as was the case at the begining of 2023 in Oltenia.

A possible continuation of this study envisages the use of software that performs stability analysis based on finite elements or the finite differences method [49–53], 3D modeling [54–58] and probabilistic approaches [59–62].

The more important research that will continue this study should focus on resizing the geometric elements (height and slope angle) originally designed for the open pits and waste dumps in Oltenia. Such a study, which takes into account the new seismic context of the area, would be able to ensure safety at work, avoid damage or destruction of machinery or even prevent injuries or loss of human life. For resizing, there are a number of classic methods for determining the geometric elements of the slopes (grapho-analytical procedures: Hoek–Bray, Fellenius, etc.) [1, 2, 17], as well as modern methods based on numerical analyses [63, 64].

7 CONCLUSIONS

In some situations (for reasons related to ensuring the necessary lignite for the energy sector in a timely manner) the mining operator tends to adopt for the development area of the open pit similar geometries of the working and dumping fronts to those of the past, taking into account especially the technical characteristics and possibilities of the equipment (mainly of the BWEs and spreaders), and to a lesser extent the morphological and stratigraphic changes (which also involve changes in the resistance characteristics of the rocks that make up the slopes). In these conditions, the risk of slope slides increases, which, in turn interrupts the productive process, but can also result in the partial or total destruction of machinery or even loss of human life.

This is also the case of the Jilț North open pit, where, following stability analyses, it was proven that two of the designed steps, T1 and T3, have inadequate stability reserves (in fact, based on the results, they are unstable) under static conditions, which implies a high risk of slope sliding, either superficial or involving larger volumes of rocks.

Under static conditions, the rest of the working and dumping steps can be considered stable, and thus the mining activities can be continued under safe conditions.

The situation changes radically when we consider the action of a seismic event.

Thus, for all of the analyzed slopes, the stability factor becomes sub-unit, which translates into a loss of balance. This state of instability significantly increases the risk of landslides involving the displacement of significant volumes of material, endangering the machinery operating in the open pits or on the dumps and the safety of the personnel.

This is the reason why the mining operators and researchers must find appropriate solutions, viable both technically and financially, that can prevent the occurrence of landslides even in case of catastrophic events, such earthquakes.

For this purpose, at present, there is available a wide pallet of methodologies and procedures, starting from the classic ones, going to modern 3D and dynamic modeling and even involving the use of AI.

The present study makes an important contribution to current open pit lignite mining in Romania, by making available to mining operators information about the stability conditions of the Jilț North open pit, some relatively simple but effective technical solutions to increase the stability reserve of the working fronts, so that the extractive activity can continue under safe conditions, and suggestions about future research themes and investigation methods.

The results of this study can, to a good extent, be extrapolated for other lignite open pits in the mining basin of Oltenia that are developed in similar conditions (in hilly regions, with similar geology and tectonics, with similar working technologies and located at comparable distances from the seismically active area): Jilț South, Roșia de Jiu, Pinoasa, Tismana, Lupoaia, Roșiuța, Oltețu and Panga.

At the same time, we appreciate that, this study is also useful in the process of academic training of future mining specialists (bachelor, master and doctoral students), being a useful material for seminars, projects and laboratories.

This paper represents a synthesis of the original articles listed in the references section as no. 1, 26, 33 and 34.

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CONTRIBUTION TO THE DEVELOPMENT OF GEODETIC NETWORK

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Abstract: *The topographic basis made for drawing and conducting underground works (mining, hydrotechnical, communication routes, special) is dependent, in some situations, on geodetic points that must be determined on the surface for this purpose. Geodetic points are obtained by developing the higher order geodetic network using methods that ensure the necessary precision, but also the efficiency of the measurement and calculation operations used. On the theoretical content, the paper presents the current known methods, on the one hand, and the possibilities of improvement, on the other hand.*

Key words: *mining surveying, topographic underground networks, topographic measurements*

1. INTRODUCTION

The quality of the topographic base materialized underground is mainly ensured by the quality of the geodetic works carried out on the surface. The distribution of geodetic points, their marking and signaling, the performance and processing of measurements, the analysis of accuracies and their propagation mode are taken into account.

The processing of measurements and the calculation of accuracies is an important step in this process. On a specific case, the corresponding scientific analysis is presented below.

2. CONTENT OF THE PAPER

The geodetic points $A, B, C, D, P_1, P_2, P_3$ (Figure 1) whose coordinates (x, y) are known (given quantities) are considered.

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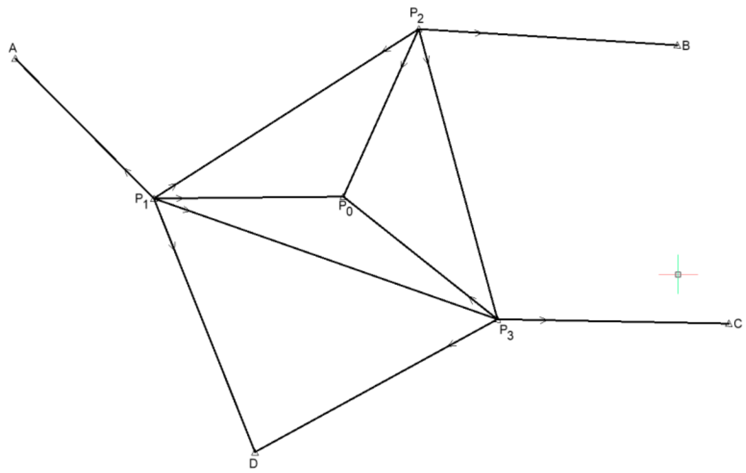

Figure 1. Triangulation network

The directions marked by arrows in the figure (measured quantities) are known from the measurements.

The coordinates of the point $P_0(x_0, y_0)$ are determined.

By using the coordinate variation method [1, 2, 3], the system of equations is formed (1), (2):

$$-\Delta z_1 + l_{1A} = v_{1A}$$

$$-\Delta z_1 + l_{12} = v_{12}$$

$$a_{10}\Delta x_0 + b_{10}\Delta y_0 - \Delta z_1 + l_{10} = v_{10}$$

$$-\Delta z_1 + l_{13} = v_{13}$$

$$-\Delta z_1 + l_{1D} = v_{1D}$$

$$-\Delta z_2 + l_{2B} = v_{2B}$$

$$-\Delta z_2 + l_{23} = v_{23}$$

$$a_{20}\Delta x_0 + b_{20}\Delta y_0 - \Delta z_2 + l_{20} = v_{20} \qquad (1)$$

$$-\Delta z_2 + l_{21} = v_{21}$$

$$-\Delta z_3 + l_{3C} = v_{3C}$$

$$-\Delta z_3 + l_{3D} = v_{3D}$$

$a_{30}\Delta x_0 + b_{30}\Delta y_0 - \Delta z_3 + l_{30} = v_{30}$

System (1) has 12 equations (how many directions are measured) and 5 unknowns $(\Delta x_0, \Delta y_0, \Delta z_1)$ $\Delta z_2, \Delta z_3$.

It is specified that:

$$x_1 = x_0 + \Delta x_0 \quad (2)$$
$$y_1 = y_0 + \Delta y_0$$

where:

$x_{0,} y_0$ are the provisional coordinates of the point P_0, obtained by a simple forward intersection, and $\Delta x_0, \Delta y_0$are their probable corrections.

The number of equations being greater than the number of unknowns [4], it is solved using the theory of indirect measurements of the same precision (3).

As a result, the system of equations (1) is written:

$$Ax - l = v \quad (3)$$

by solving which we obtain (4):

$$x = (A'A)^{-1}A'l \quad (4)$$

x - column matrix of unknowns
A - rectangular matrix of coefficients of unknowns
l - matrix of free terms

The coefficients of unknowns are obtained according to the measured orientations and calculated using the known quantities (given and measured).

In the system of equations (3) there are unknowns $(\Delta z_1, \Delta z_2, \Delta z_3)$ that are of no interest (do not need to be determined).

They can be limited, using equivalent systems of equations [5].

For example, for the directions measured in point P_1, the equivalent system is (5):

$l_{1A,} = v_{1A}$

$l_{12} = v_{12}$

$$a_{10}\Delta x_0 + b_{10}\Delta y_0 + l_{10} = v_{10} \quad (5)$$

$l_{13} = v_{13}$

$l_{1D} = v_{1D}$

$$a_{10}\frac{i}{\sqrt{n_1}}\Delta x_0 + b_{10}\frac{i}{\sqrt{n_1}} + 0 = v_{10}$$

n_1= 5 the number of directions measured in point P_1

$$i = \sqrt{-1}$$

In the same way, the equivalent systems corresponding to the directions measured in points P_2 and P_3 are written.

Consequently, the system of normal equations of the system of error equations (1), turns into a system of normal equations with two dimensions.

Let's go back to the system (6):

$$-\Delta z_1 + l_{1A} = v_{1A}$$

$$-\Delta z_1 + l_{12} = v_{12}$$

$$a_{10}\Delta x_0 + b_{10}\Delta y_0 - \Delta z_1 + l_{10} = v_{10} \tag{6}$$

$$-\Delta z_1 + l_{13} = v_{13}$$

$$-\Delta z_1 + l_{1D} = v_{1D}$$

In the system of normal equations corresponding to system (6) the equation is part:

$$-a_{10}\Delta x_0 - b_{10}\Delta y_0 + n_1\Delta z_1 = 0 \tag{7}$$

Equation (7) follows:

$$\Delta z_1 = \frac{a_{10}}{n_1} \quad \Delta x_0 + \frac{b_{10}}{n_1}\Delta y_0 \tag{8}$$

With the relation (8) the system becomes:

$$-\frac{a_{10}}{n_1}\Delta x_0 - \frac{b_{10}}{n_1}\Delta y_0 + l_{1A} = v_{1A}$$

$$-\frac{a_{10}}{n_1}\Delta x_0 - \frac{b_{10}}{n_1}\Delta y_0 + l_{12} = v_{12}$$

$$\left(a_{10} - \frac{a_{10}}{n_1}\right)\Delta x_0 - \left(b_{10} - \frac{b_{10}}{n_1}\right)\Delta y_0 + l_{10} = v'_{10} \tag{9}$$

$$-\frac{a_{10}}{n_1}\Delta x_0 - \frac{b_{10}}{n_1}\Delta y_0 + l_{13} = v_{13}$$

$$-\frac{a_{10}}{n_1}\Delta x_0 - \frac{b_{10}}{n_1}\Delta y_0 + l_{1D} = v_{1D}$$

But, the first two equations and the last two of (9) have identical coefficients, so they are equivalent to the equation:

$$-\frac{a_{10}}{n_1}\Delta x_0 - \frac{b_{10}}{n_1}\Delta y_0 - \frac{l_{10}}{n-1} = v''_{10} \tag{10}$$

with the weight $n_1 - 1$

Equation (10) is equivalent to the equation (11):

$$-\frac{a_{10}}{n_1}\sqrt{n_1 - 1}\,\Delta x_0 - \frac{b_{10}}{n_1}\sqrt{n_1 - 1}\,\Delta y_0 - \frac{l_{10}}{n-1}\sqrt{n_1 - 1} = v'_{10} \tag{11}$$

with the weight = 1

In conclusion:
The system of equations (5) is equivalent to the system (12):

$$\left(a_{10} - \frac{a_{10}}{n_1}\right)\Delta x_0 + \left(b_{10} - \frac{b_{10}}{n_1}\right)\Delta y_0 + l_{10} = v'{}_{10} \tag{12}$$

$$-a_{10}\frac{\sqrt{n_{1-1}}}{n_1}\,\Delta x_0 - b_{10}\frac{\sqrt{n_{1-1}}}{n_1}\Delta y_0 - \frac{l_{10}}{n_{n-1}}\sqrt{n_1 - 1} = v''_{10}$$

For the situation in figure (1) the system of error equations is (13):

$$\left(a_{10} - \frac{a_{10}}{5}\right)\Delta x_0 + \left(b_{10} - \frac{b_{10}}{5}\right)\Delta y_0 + l_{10} = v'{}_{10}$$

$$\left(a_{20} - \frac{a_{20}}{4}\right)\Delta x_0 + \left(b_{20} - \frac{b_{20}}{4}\right)\Delta y_0 + l_{20} = v'{}_{20} \tag{13}$$

$$\left(a_{30} - \frac{a_{30}}{3}\right)\Delta x_0 + \left(b_{30} - \frac{b_{30}}{3}\right)\Delta y_0 + l_{30} = v'{}_{30}$$

$$-a_{10}\,\frac{\sqrt{4}}{5}\,\Delta x_0 - b_{10}\,\frac{\sqrt{4}}{5}\,\Delta y_0 - \frac{\sqrt{4}}{5}l_{10} = v''_{10}$$

$$-a_{20}\,\frac{\sqrt{3}}{4}\,\Delta x_0 - b_{20}\,\frac{\sqrt{3}}{4}\,\Delta y_0 - \frac{\sqrt{3}}{4}l_{20} = v''_{20}$$

$$-a_{30}\ \frac{\sqrt{2}}{3}\ \Delta x_0 - b_{30}\ \frac{\sqrt{2}}{3}\ \Delta y_0 - \frac{\sqrt{2}}{3} l_{30} = v_{30}''$$

So, the initial system of 12 equations and 5 unknowns has been transformed into a system of 6 equations with two unknowns.

The system of equations corresponding to the directions measured at the point P_1can be written in the form (14):

$$a_{10}\Delta x_0 + b_{10}\Delta y_0 + l_{10} = v_{10} \quad \text{with the weight 1} \tag{14}$$

$$a_{10}\Delta x_0 + b_{10}\Delta y_0 + 0 = v_{10}' \qquad \text{with the weight } -\frac{1}{n_1}$$

But, the system of equations (14) can be further transformed into the equivalent system of equations of the form:

$$a_{10}\Delta x_0 + b_{10}\Delta y_0 + \frac{n_1}{n_1 - 1} = v_{10}'' \tag{15}$$

with the weight:

$$[p] = 1 - \frac{1}{n_1} = \frac{n_1}{n_1 - 1} \tag{16}$$

The system of equations (16) is transformed into the system of equations equivalent to the form:

$$a_{10}\sqrt{\frac{n_{1-1}}{n_1}}\Delta x_0 + b_{10}\sqrt{\frac{n_{1-1}}{n_1}}\Delta y_0 + \frac{n_1}{n_1 - 1}\sqrt{\frac{n_{1-1}}{n_1}}\, l_{10} = v_{10}'' \quad \text{with the weight 1} \tag{17}$$

In conclusion, for the directions measured at the point P_1un number equal to n_1, only one equation (17) can be written.

As a result, for the 12 directions measured at points P_1, P_2, P_3 si the system of error equations has the form (18):

$$a_{10}\sqrt{\frac{4}{5}}\Delta x_0 + b_{10}\sqrt{\frac{4}{5}}\Delta y_0 + \frac{5}{4}\sqrt{\frac{4}{5}}\, l_{10} = v_{10}$$

$$a_{20}\sqrt{\frac{3}{4}}\Delta x_0 + b_{20}\sqrt{\frac{3}{4}}\Delta y_0 + \frac{4}{3}\sqrt{\frac{3}{4}}\, l_{20} = v_{20} \tag{18}$$

$$a_{30}\sqrt{\frac{2}{3}}\Delta x_0 + b_{30}\sqrt{\frac{2}{3}}\Delta y_0 + \frac{3}{2}\sqrt{\frac{2}{3}}\, l_{30} = v_{30}$$

In conclusion, by using equivalence methods, the initial system of equations turns into a system of equations of 3 equations.

For the directions measured in the geodetic network with 4 fixed points and one variable point (figure 1), the calculation scheme for the variant with the equation $i = \sqrt{-1}$ will be presented (Table 1).

Table 1. Calculation scheme for the variant with the equation i= √ (-1)

PS	PV	Direction coefficients		Free terms
		a	b	$l = -(\theta^m - \theta^C)$
P_1	A	-	-	l_{1A}
	P_2	-	-	l_{12}
	P_0	a_{10}	b_{10}	l_{10}
	P_3	-	-	l_{13}
	D			l_{1D}
[ ]		$\frac{i}{\sqrt{5}} a_{10}$	$\frac{i}{\sqrt{5}} b_{10}$	0
P_2	P_1	-	-	l_{21}
	B	-	-	l_{2B}
	P_3	-	-	l_{23}
	P_0	a_{20}	b_{20}	l_{120}
[ ]		$\frac{i}{\sqrt{4}} a_{20}$	$\frac{i}{\sqrt{5}} b_{20}$	0
P_3	P_0	a_{30}	b_{30}	l_{30}
	C	-	-	l_{3C}
	D	-	-	l_{3D}
[ ]		$\frac{i}{\sqrt{3}} a_{30}$	$\frac{i}{\sqrt{3}} b_{30}$	0

Switching from systems to systems of equivalent equations also simplifies the calculation of accuracies (19).

Thus:

$$m_{\Delta x_0} = m_0 \sqrt{Q_{11}}$$

$$m_{\Delta y_0} = m_0 \sqrt{Q_{22}} \tag{19}$$

Where (20):

$$-m_0 = \sqrt{\frac{[vv]}{n-k}} \tag{20}$$

n – the number of equations in the initial system (13)
k – total number of unknowns (6)

Q_{11}, Q_{22} - the coefficients of weight of unknowns

But in general (21):

$$Q = (A'A)^{-1} = \begin{pmatrix} Q_{11} & Q_{12} \\ Q_{21} & Q_{22} \end{pmatrix} \tag{21}$$

3. CONCLUSIONS

In mining, mining works opening and preparation are very important technical point, have permanent character as the embodiment are high-volume and represent goals that require special financial efforts.

On the other hand the implementation of the projects elaborated in this area is done with topographic methods that have special character by conditions that run and by their quality. The papers presented were studied independent routes used to establish the base topographic topographical elements that lead workings in their execution and have character punching shear.

From angular and distance error study conducted independent polygonal paths, there exists an optimal point where the punching shear is minimal transversal deviation is determined and its position.

The methods of processing the measurements and the precision analyses presented in the paper stand out for their originality, efficiency and quality. These are methods that can be easily applied in practice and have a high degree of precision.

In order to reduce the volume of computational operations, systems of equivalent equations are introduced in order to transform the system of error equations into systems of equations that are simple in form and with the possibility of being written directly from the sketch of the geodetic network.

The content of the work fully meets the purpose. The theoretical content is accessible to specialists with higher education in the field.

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CORRELATIONS BETWEEN WEIGHTING COEFFICIENTS CORRESPONDING TO THE MEASUREMENT GROUPS

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Abstract: *The information base needed to solve geodetic and topographic problems consists of measurements of angles and distances. According to their presentation and conditions, measurements are grouped and defined differently and consequently processing methods are different. The purpose of the processing operations is the same, namely to determine the probable values of the measured quantities and their accuracy ranges, expressed by weight coefficients. For the mining topography activity, the weighting coefficients have an important role in the decision act regarding the safe drawing and management of mining works.*

Key words: *mining surveying, topographic underground networks, errors, topographic measurements*

1. CONTENT OF THE PAPER

It is known that conditional measurements can be reduced to indirect measurements [1]. Respectively, the system:

$$\begin{aligned} &a_1 v_1 + a_2 v_2 + \cdots + a_n v_n + \omega_1 = 0 \\ &b_1 v_1 + b_2 v_2 + \cdots + b_n v_n + \omega_2 = 0 \\ &r_1 v_1 + r_2 v_2 + \cdots + r_n v_n + \omega_r = 0 \end{aligned} \tag{1}$$

It can be written as:

$$\begin{aligned} &v_1 = A_1 v_{r+1} + B_1 v_{r+2} + \cdots + H_1 v_n + L_1 \\ &v_2 = A_2 v_{r+1} + B_2 v_{r+2} + \cdots + H_2 v_n + L_2 \\ &v_r = A_r v_{r+1} + B_r v_{r+1} + \cdots + H_r v_{r+1} + L_r \\ &v_{r+1} = v_{r+1} \\ &v_{r+2} = \qquad + v_{r+2} \\ &\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ &v_n = \cdots \ldots \ldots \ldots \ldots \ldots \ldots v_n \end{aligned} \tag{2}$$

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$v_{r+1} = x_1$; $v_{r+2} = x_2$; …; $v_n = x_h$

then system (2) is written:

$$v_i = A_i x_1 + B_i x_2 + \cdots + H_i x_h \qquad (3)$$
$$i = 1, 2, \dots, n$$

Systems of equations written in general form correspond to conditional measurements (1) and indirect measurements (3).

In matrix writing they have the form:

$$B' v = \omega \qquad (4)$$
$$Ax - l = v \qquad (5)$$

In which:

$$B = \begin{pmatrix} a_1 & b_1 & \cdots & r_1 \\ a_2 & b_2 & \cdots & r_2 \\ \dots & \dots & \dots & \dots \\ a_n & b_n & \cdots & r_n \end{pmatrix}$$

$$A = \begin{pmatrix} A_1 & B_1 & \cdots & H_1 \\ A_2 & B_2 & \cdots & H_2 \\ \dots & \dots & \dots & \dots \\ A_n & B_n & \cdots & H_n \end{pmatrix}$$

$$V = \begin{pmatrix} v_1 \\ v_2 \\ \cdots \\ v_n \end{pmatrix}$$

$$x = \begin{pmatrix} x_1 \\ x_2 \\ \cdots \\ x_n \end{pmatrix}$$

$$\omega = -\begin{pmatrix} \omega_1 \\ \omega_2 \\ \cdots \\ \omega_r \end{pmatrix}$$

$$l = \begin{pmatrix} L_1 \\ L_2 \\ \cdots \\ L_n \end{pmatrix}$$

The measurements in the systems of equations (4) and (5) can be of equal or different precision (general case).

The general case is further analyzed in context, with the following notes:

$Q_{l\bar{l}}$ - matrix of correction weighting coefficients in the system of equations (1)
$Q_{x\bar{x}}$ - matrix of correction weighting coefficients in the system of equations (2)

In solving problems regarding the processing of measured quantities, situations arise when the connection between Q_{ll} and Q_{xx} is necessary.
It is known that the matrix of unknowns in system (2) is:

$$x = (A'pA)^{-1}A'l \tag{6}$$

According to equality (6) the system of equations (5) becomes:

$$A(A'pA)^{-1}A'l - l = v$$

If (x) are the probable values of the corrections, then they are:

$$(x) = A(A'pA)^{-1}A'l + l - l$$
$$(x) = A(A'pA)^{-1}A'l \tag{7}$$

From the tie (7) it can be written:

$$Q_{ll} = A(A'A)^{-1}A'pp^{-1}pA(A'pA)^{-1} \tag{8}$$

Or:

$$Q_{ll} = A(A'pA)^{-1}A'$$

Note:

$$Q_{xx} = (A'pA)^{-1}$$

And

$$Q_{ll} = AQ_{xx}A' \tag{9}$$

Equality (9) is multiplied on the left by A'p and on the right by pA and results:

$$A'pQ_{ll}pA = A'pAQ_{xx}A'pA$$

Or:

$$A'pQ_{ll}pA = A'pA$$

Respectively:

$$Q_{xx} = (A'pAQ_{ll}pA)^{-1} \tag{10}$$

For conditional measurements, the analysis of accuracies can be performed directly, as follows:
The probable corrections obtained by solving the system (4) are given by the expression:

$$v = p^{-1}BK \tag{11}$$

In which K is obtained with equality:

$$K = (B'QB)^{-1}\omega$$

Where:

$$Q = p^{-1} = \begin{pmatrix} \frac{1}{p_1} & \dots & \dots \\ \dots & \frac{1}{p_2} & \dots \\ \dots\dots\dots\dots\dots \\ \dots & \dots & p_n \end{pmatrix}$$

For the calculation of the weighting coefficients and corrections, it is written:

$$(x) = l + v \tag{12}$$

Where:

$$v = QBK = QB(B'QB)^{-1}\omega \tag{13}$$

But how:

$$\omega = -B'l$$

Result:

$$(x) = -[E - QB(B'QB)^{-1}]l \tag{14}$$

Consequently, the weight coefficients of the quantities (x) are obtained from (14) by writing:

$$Q_{ll} = [E - QB(B'QB)^{-1}B']Q[E - B(B'QB)^{-1}B'Q]$$

and:

$$Q_{ll} = Q - QB(B'QB)^{-1}B'Q \tag{15}$$

It is found that the correlation between the coefficients of weight established with equality (9) provides a simpler and consequently more efficient way to use in practice.

2. EXAMPLE

In order to understand the calculation procedure, we consider a simple case regarding the angles measured in a geodesic triangle, (Figure 1) [2], [3], [4].

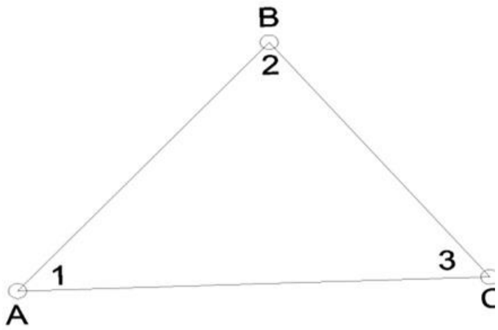

Figure 1. Geodesic triangle

The values of the angles are:

$1 = 57^{g}69^{c}07^{cc}$
$2 = 66^{g}87^{c}06^{cc}$
$3 = 75^{g}43^{c}93^{cc}$

The sum of the angles measured is $200^{g}00^{c}06^{cc}$.

If (1), (2), (3) are the probable values of the angles then:

$(1) = 1 + v_1$
$(2) = 2 + v_2$
$(3) = 3 + v_3$

And then:

$(1) + (2) + (3) = 200^{g}$

Respectively:

$v_1 + v_2 + v_3 + 6 = 0$

But, we can write:

$$\begin{aligned} -x_1 - x_2 - 6 &= v_1 \\ x_1 \qquad\qquad &= v_2 \\ x_2 \quad &= v_3 \end{aligned}$$

It was noted:

$$v_2 = x_1$$
$$v_3 = x_2$$

The weight coefficients of the measurements to be determined are:

$$Q_{xx} = (A'A)^{-1}$$
$$A' = \begin{pmatrix} -1 & 1 & 0 \\ -1 & 0 & 1 \end{pmatrix}$$
$$Q_{xx} = \begin{pmatrix} 0{,}666 & -0{,}333 \\ -0{,}333 & 0{,}666 \end{pmatrix}$$

The weighting coefficients of the corrections v_1, v_2, v_3 are:

$$Q_{ll} = AQ_{xx}A' = \begin{pmatrix} 0{,}666 & -0{,}333 & -0{,}333 \\ -0{,}333 & 0{,}666 & -0{,}333 \\ -0{,}333 & -0{,}333 & 0{,}666 \end{pmatrix}$$

and vice versa:

$$Q_{xx} = (A'Q_{ll}A)^{-1}$$
$$Q_{ll} = E - B(B'B)^{-1}B^1$$
$$B^1 = (1, 1, 1)$$

$$Q_{ll} = \begin{pmatrix} \frac{2}{3} & -\frac{1}{3} & -\frac{1}{3} \\ -\frac{1}{3} & \frac{2}{3} & -\frac{1}{3} \\ -\frac{1}{3} & -\frac{1}{3} & \frac{2}{3} \end{pmatrix}$$

$$Q_{xx} = \begin{pmatrix} 0{,}666 & -0{,}333 \\ -0{,}333 & 0{,}666 \end{pmatrix}$$

3. CONCLUSIONS

The determination of weight coefficients requires knowledge of the theory of processing measured quantities.

The links between the weight coefficients can be made simply using the matrix calculation. They are useful, simple and require a small amount of compute.

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STUDY OF LAND COVER FROM FÂRDEA ADMINISTRATIVE TERRITORY, TIMIȘ COUNTY

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Abstract: *Soil, the main natural means of production, is the layer forms on the land surface, in many years under the influence of climatic conditions on parental materials. The fertility of a soil depends directly on the physical and chemical properties of the respective soil. The soil, as an open ecological system, is connected to the environment, through a continuous flow of matter and energy. The purpose of the paper is the collection, processing and accumulation of scientific data related to environmental factors, the geographical characteristics of the area, soil resources, data related to the nature and intensity of the limiting factors, the qualitative evaluation of the lands and their productivity. The relevance of the theme is highlighted mainly in the field of meadow conservation in the studied area, but also in the identification, protection and conservation of soil resources. The study of the specific natural conditions of the territorial administrative unit Fârdea was carried out, respectively the relief conditions, hydrography and hydrology, climate, soil resources, elements of flora and fauna (biodiversity). Observations were also made regarding the meadows, the morphological, physical and chemical characteristics of the soils on this area, from the perspective of the characterization of the soil cover, the determination of the quality class for the pasture use category. The types of soils identified on the researched territory are Regosols, Alluviosols, Eutricambosols and Luvosols. The limiting factors that influence the quality of the soil cover within the Fârdea cadastral territory are mainly dimensioned by: soil reaction with low values, the slope of the land and the danger of soil erosion, the degree of subsidence, the reserve of humus.*

Key words: *morphologic, soil, land cover, texture, properties*

1. INTRODUCTION

The soil, as a means of production in agriculture and horticulture, presents certain particularities, which distinguish it from other means of production. Thus, soil is a natural means of production, which forms and evolves on the surface of the land, over time and under the influence of environmental conditions. Also, unlike other means of production that wear out through use, the soil, if used rationally, not only does not decrease its fertility, but, on the contrary, can increase it. [1,2]

Agricultural practice shows that yields can increase with the help of certain measures, such as: the use of advanced high-tech machines and tools; the use of fertilizers, amendments and control substances; by carrying out irrigation, drying, drainage, damming, prevention and erosion control works; by improving the work and

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knowledge of man; by applying the results obtained in scientific research, etc. [3, 6, 7, 8]

Being an open ecological system, it has strong connections with the environment, by a continuous exchange of matter, energy and information. In its long evolution, under the action of natural factors and agricultural culture, the soil tends towards a stationary state, characterized by equalizing tendencies of imports and exports of energy and substances. [9]

The importance of the addressed topic derives from the fact that the properties of the soil (land) are extremely differentiated in the territory, due to the variation of environmental factors and conditions, and its relevance being highlighted mainly in the field of legal circulation of land but also in profitability from an economic point of view in the use of different agricultural areas in the production process. [6, 10, 11]

The purpose of this paper is the identification of researched area, collection of soil samples, processing of this scientific data related to environmental factors, the characterization of the area from geographical point of view, characterization of soil resources, identification of limiting factors, the qualitative assessment of lands and their productivity.

In order to achieve the proposed objectives, the research activity consisted in the theoretical documentation, respectively the establishment of the specialized bibliography, books and specialized scientific works, supplemented with own research [20].

2. MATERIALS AND METHODS

The purpose of this study is to obtain a fund of information regarding the technical and fertility characteristics of soils for pastoral management.

The objectives of this study are the following:

- the identification, delimitation and inventory of soil-land units, by making the map and the legend of soil.
- morphological, physical, hydrophysical and chemical characterization of the identified soil units from the map.
- crediting the land and determining the suitability for pastures
- highlighting the nature and intensity of the limiting and/or restrictive factors of agricultural production.
- grouping of lands according to suitability (pastures).
- determining the state of supply/assurance of soils with nutrients, as well as the reaction of soils (agrochemical characterization of soils).
- identifying, delimiting and inventorying the types of soil/land degradation, establishing land restrictions for different uses and establishing appropriate agropedo-ameliorative and anti-erosion measures.

The soil samples were analyzed in the OSPA Timiş laboratories. The following analyzes were performed [20]:

- granulometric analysis (%) – Kacinski method;
- apparent density (DA, g./cm3) – metal cylinder method;
- density (D., g. /cm^3) – pycnometer method;

- hygroscopicity (CH %) – Mitscherich method;
- pH (in H_2O) – potentiometric method;
- humus % - Walkley – Black method;
- accessible phosphorus (mobile), ppm – Egner-Riehm-Domingo method;
- available (mobile) potassium, ppm - Egner-Riehm-Domingo method;

Through different calculation methods were determined:

- total porosity, PT(%)
- aeration porosity, PA %
- wilting coefficient, CO %
- field capacity CC%
- total capacity CT %
- useful water capacity CU%
- maximum yield capacity
- degree of subsidence GT (%)
- humus reserve (t/ha)
- nitrogen index IN
- degree of saturation in bases V%

The interpretation of the data, the characterization of the natural environment, the analysis of the limiting factors of agricultural production as well as the assessment of agricultural land, were carried out in accordance with the “Methodology for the Development of Pedological Studies” (vol. I, II, III) developed by ICPA Bucharest under the auspices of ASAS Bucharest in 1987 , the “Romanian Soil Taxonomy System” (SRTS) from 2012, as well as MAAP Order 223/28.05.2002, respectively based on the theoretical and practical materials from the work "Guide for field description of soil profile soil and specific environmental conditions, developed by the National Research and Development Institute for Pedology, Agrochemistry and Environmental Protection in Agriculture - ICPA Bucharest, in 2009. [4, 5]

Within the soil profile, the samples were collected on pedogenetic horizons, both in natural (unmodified) and modified settlement.

The collection of soil samples in the natural setting (unmodified) for the characterization of certain physical and hydrophysical characteristics was done in metal cylinders of known volume at the momentary humidity of the soil and in cardboard boxes (specially made) for its micromorphological characterization. [12-15]

The collection of samples in a modified arrangement, for physico-chemical and partially biological characterization, was done in bags for each genetic horizon [16].

Also, in this paper, based on the pedological data, a series of thematic maps were made using Geographic Information Systems (GIS).

3. RESULTS AND DISCUSSION

From a geomorphological point of view, the analyzed territory is part of the great geomorphological unit of the Western Piedmont, namely the Poiana Rusca Piedmont. It takes place in the western part of the Poiana Rusca Mountains, up to the

Mures Valley in the north, Bega in the west and Timis in the south, with altitudes between 200-500 m [17].

The Fârdea depression is the largest in the area, extending over a length of 10 km and a width of 3-4 km. It has the shape of a circular arc, with the opening towards Poiana Rusca mountains, having to the south, Piedmont formations with different levels of erosion (Fig. 1.a. and b.).

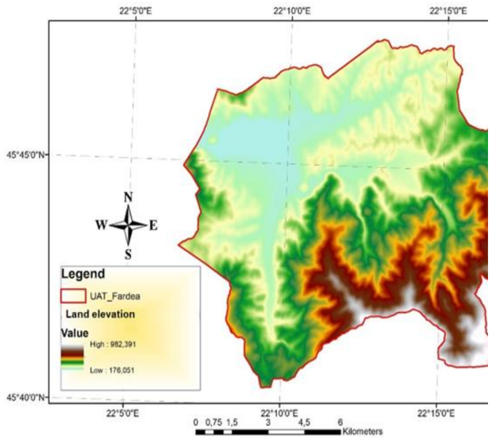

Figure 1.a. Land elevation from Fârdea

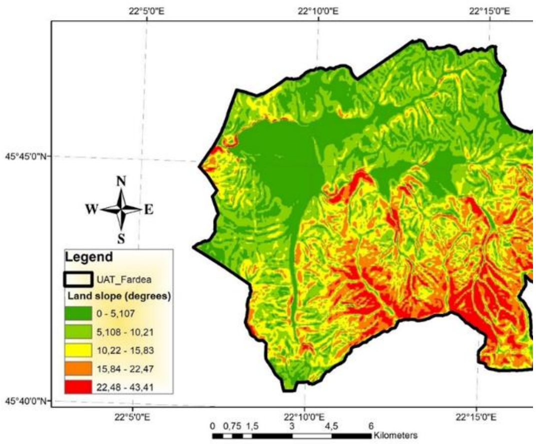

Figure 1.b. Slope map from Fârdea

Fârdea commune is locatedin the in the west of Romania, in the eastern extremity of Timiş county, approximately 35 km NE from Lugoj and 90 km from Timișoara (Fig. 2.a. and b.).

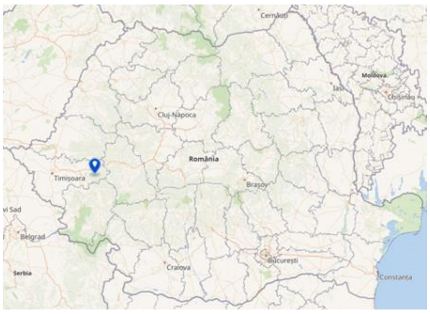

Figure 2.a. Location of the Fârdea area in the Romanian territory (source Wikipedia)

Figure 2.b. Location of the Fârdea area in the Timis County (source Wikipedia)

Fârdea commune has in its componence the following villages: Fârdea (administrative center), Hăuzeşti, Drăgsineşti, Mâtnicu Mic, Gladna Montană, Gladna Română and Zolt.

The cadastral territory of 13107 ha, of which 4695 ha (35.82%) is agricultural land, 7,726 ha (35.82%) being occupied by forests, is located almost entirely in the great geomorphological unit of the Western Piedmont, namely the Poiana Ruscă Piedmont (Fig. 3.a. and b).

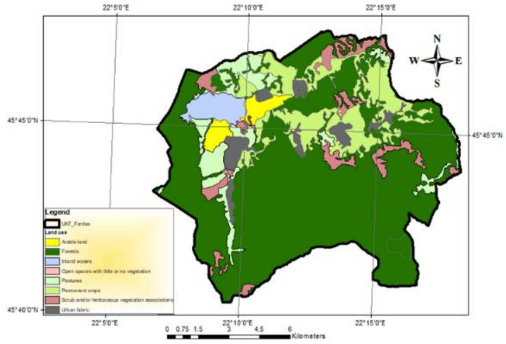

Figure 3.a. Land use in Fârdea locality

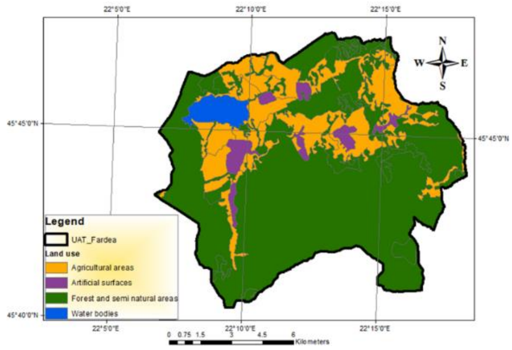

Figure 3.b. Land use in Fârdea locality

Hydrographically, the mentioned perimeter belongs to the hydrographic basin of the Bega River, the most important water course being the Gladna River, which has a length of over 30 km and a catchment area of approx. 250 km^2 and a flow rate of approx. 1.1 m^3/s.

The river flows upstream from Gladna Română to the heart of the Poiana Ruscă Mountains, the catchment area of the springs being below the peak of Bordarul (865.0 m).

The Surduc reservoir is located at a distance of about 90 km east of Timişoara and about 30 km east of Lugoj on the administrative territory of the commune of Fârdea.

The flowing waters that feed Lake Surduc are: Hăuzeasca stream, from north to south, Meuniscel stream, which flows from northeast to southwest, Gladna stream, which flows from east to west.

The mentioned territory is characterized by a moderate temperate continental climate, with an average multiannual temperature of 9.1^{o}C, with an average multiannual precipitation of 840.5 mm, with shorter and milder winters and hot and long summers.

Depending on the influence and action of the complex of pedogenetic factors (relief, rocks, climate, hydrology, etc.) as well as due to the human intervention, within the researched area, the current edaphic cover (Fig. 4) is very varied.

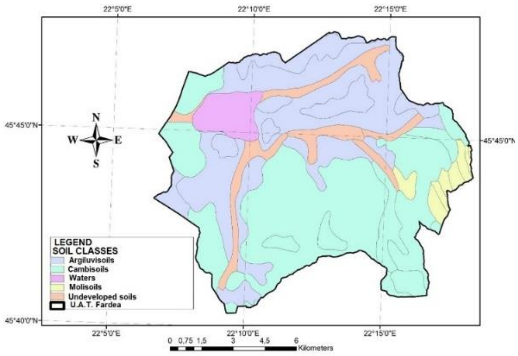

Figure 4. Distribution of soil classes in UAT Fârdea

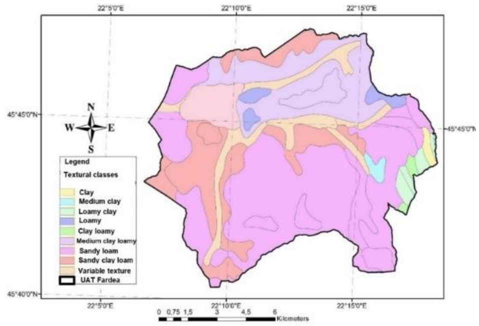

Figure 5. Textural classes of the soils of UAT Fârdea

The following soil types were identified on the researched territory: Regosoils (11.39%), Alluviosoils (0.48%), Eutricambosoils (10.87%) and Luvosoils (77.26%).

Taking into account the existing landforms within the Fârdea UAT, the nature of the parental material as well as the pedogenesis processes, a map of the soil texture within the locality radius was made (fig. 5).

The main soil type from pastures of Fârdea UAT are presented in table 1.

Table 1. The soil units identified on the UAT Fârdea pastures

No. US	Surface		Ground unit	Ground water level
	Ha	%		
1	214.47	11.39	Eutric regosol, medium loamy sand/ medium loamy sand	≥ 10.1
2	9.00	0.48	Clayed alluviosoil, weakly clayey, coarse loamy sand/coarse sand,	2-3
3	204.67	10.87	Gleyc Eutricambosol, moderately glayed, medium sandy loam/medium sandy loam,	2-3
4	28,16	1.50	Typical Luvosol, dusty sandy loam/ dusty sandy loam,	≥ 10.1
5	47.49	2.52	Stagnant Luvosol, weak stagnoglayed, medium clay/medium clay loam,	≥ 10.1
6	41.69	2.21	Stagnant Luvosol, weak stagnogleyed, medium sandy loam / medium loamy sand,	≥ 10.1
7	225.72	11.99	Stagnant Luvosol, weak stagnoglayed, coarse sandy loam/medium loam.	≥ 10.1
8	335.01	17.79	Stagnant Luvosol, weak stagnogleyed, silty loam/medium loam,	≥ 10.1
9	517.46	27.49	Stagnant luvosol, moderate stagnogleyed, medium loamy sand/ medium loamy sand,	≥ 10.1
10	144.05	7.65	Stagnant Luvosol, Moderate Stagnogleyed, Medium Loam/Loamy Clay,	≥ 10.1
11	35.88	1.91	Stagnant Luvosol, moderate stagnogleyed, dusty sandy loam/dusty loam,	≥ 10.1
12	63.21	3.36	Lithic Luvosol, medium sand/medium sand,	≥ 10.1
13	15.82	0.84	Luvosol, heavily stagnoglazed, fine sandy loam/medium clay loam,	≥ 10.1

The morphological, physical and chemical characterization of the representatives soils from Fârdea pastures are presented in the following:

SOIL UNIT (US) No. 1

Name: Eutric regosol, medium loamy sand/ medium loamy sand

Formula: RS eu, 22/22

SOIL CHARACTERISTICS

Morphological: Type profile: Ace - Ao - C

At; 0-5 cm – loamy sand, reddish brown,

Ao; 5-15 cm – loamy sand, reddish brown, C; 15-75 cm – loamy, reddish, glomerular sand;

Physics:

- the texture is loamy sand on 0-75 cm.
- high total porosity between 0-15 cm and medium between 15-75 cm;
- aeration porosity is high between 0-15 cm and medium between 15 - 75 cm;
- low apparent density between 0-15 cm and medium in the range 15-75 cm;
- small wilting coefficient between 0-75 cm;

Chemicals:

- the soil reaction is moderately acidic on 0-15 cm and weakly acidic between 15-75 cm;
- the humus reserve is very small in the first 50 cm;
- the nitrogen index is low;

Table 2. US 1 Analysis Bulletin

Depth	**cm**	**0-5**	**-15**	**-75**
Granulometric analysis		UM	UM	UM
Coarse sand (2.0 - 0.2 mm)	%	25.1	23.1	19.6
Fine sand (0.2-0.02 mm)	%	39.3	42.3	42.1
Dust (0.02 – 0.002 mm)	%	25.2	25.2	27.9
Colloidal clay (under 0.002 mm)	%	10.4	9.4	10.4
Physical clay (below 0.01 mm)	%	24.3	22.8	25.5
Specific density (Ds)	g/cm^3	2.6	2.65	2.68
Apparent density	g/cm^3	1.3	1.48	1.52
Total porosity (PT)	%	50.00	44.15	43.28
Aeration porosity (PA)	%	24.39	18.55	17.60
Grade of subsidence (GT)	%	-6.11	7.07	9.02
Coef. of hygroscopicity (CH)	%	3.07	3.63	3.72
Coef. of wilting (CO)	%	4.60	5.44	5.58
Field capacity (CC)	%	19.7	17.3	16.9
Total capacity (CT)	%	38,46	29.83	28.48
Useful water capacity (CU)	%	15.10	11.86	11.32
pH in water,	unit.pH	5.74	5.66	5.99
	t°C	24.0	24.0	24.7
Humus	%	3.12	1.90	0.81
Mobile phosphorus in Al recalculated by pH	ppm	30.70	22.78	
Mobile potassium in Al	ppm	88	78	
Reserve humus	t/ha	20.28	28.12	43.09
Sum of exchange bases (SB)	me/100 g soil	10.19	9.42	10.00
Exchangeable hydrogen (SH)		6.73	7.21	6.63
Cation exchange capacity (T)		16.92	16.63	16.63
Degree of saturation in bases (V)	%	60.22	56.64	60.19

SOIL UNIT (US) No. 3

Name: Gleic Eutricambosoil, moderately gleyed, developed on medium non-carbonate fluvial materials, medium sandy loam/medium sandy loam.

Formula: EC gc G_3 32/32

SOIL CHARACTERISTICS

Morphological: Profile of the type: Aţ-Ao-Bvg-BCg_2-CGo_3

At; 0-5 cm – sandy, brown, unstructured clay.

Ao; 5-24 cm – sandy, brown, granular clay,

Bvg 24-51 cm – sandy clay, brownish-yellow with rare rust particles (≤ 5%), prismatic,

BCg_2 51-72 cm – sandy loam, yellowish with rust spots (6-15%), prismatic,

CGo_3 72-130 cm – loamy sand, yellow rust (16-30 %).

Physics:
- the texture is medium sandy loam between 0-130 cm;
- very high total porosity between 0-5 cm and medium between 5-51 cm;
- very low apparent density between 0-5 cm and medium between 5-51 cm;
- the coefficient of wilting between 0-51 cm is small;

Chemicals:
- weak acid soil reaction up to 130 cm;
- low humus reserve;
- low nitrogen index between 0-51 cm.

Table 3. US 3 Analysis Bulletin

Depth	**cm**	**0-5**	**-24**	**-51**	**-72**	**-130**
Granulometric analysis		SM	SM	SM	SM	SM
Coarse sand (2.0 - 0.2 mm)	%	8.8	8.8	7.4	7.6	7.9
Fine sand (0.2-0.02 mm)	%	51.6	52.9	54.7	54.9	56.2
Dust (0.02 – 0.002 mm)	%	24.9	22.4	21.1	19.3	17.0
Colloidal clay (under 0.002 mm)	%	14.7	15.9	16.8	18.2	18.9
Physical clay (below 0.01 mm)	%	27.3	28.5	27.8	27.6	27.0
Specific density (Ds)	g/cm^3	2.6	2.62	2.65		
Apparent density	g/cm^3	1.18	1.47	1.43		
Total porosity (PT)	%	54.62	43.89	46.04		
Aeration porosity (PA)	%	30.78	18.46	18.44		
Grade of subsidence (GT)	%	-15.11	7.61	3.50		
Coef. of hygroscopicity (CH)	%	3.53	3.63	3.91		
Coef. of wilting (CO)	%	5.30	5.44	5.86		
Field capacity (CC)	%	20.2	17.3	19.3		
Total capacity (CT)	%	46,28	29.86	32.19		
Useful water capacity (CU)	%	14.90	11.86	13.44		
pH in water, soil:water ratio 1:2.5	unit.pH	6.25	6.24	6.39	6.58	6.85
	t°C	24.3	24.2	24.5	24.5	24.4
Humus	%	2.26	1.45	0.94		
Reserve humus	t/ha	13.33	40.50	34.95		

Depth	cm	0-5	-24	-51	-72	-130
Mobile phosphorus in Al recalculated by pH	ppm	15.68	15.86			
Mobile potassium in Al	ppm	110	87			
Sum of exchange bases (SB)	me/100 g soil	9.04	8.65	8.27	9.23	9.23
Exchangeable hydrogen (SH)		4.86	4.13	3.94	3.03	2.50
Cation exchange capacity (T)		13.90	12.78	12.21	12.26	11.73
Degree of saturation in bases (V)	%	65.04	67.68	67.73	75.28	78.69

SOIL UNIT (US) No. 4

Name: Typical Luvosoil, dusty sandy loam/dusty sandy loam,

Formula: LV ti W_2 34/34

CHARACTERISTICS OF THE SOIL

Morphologic:

Type profile: At-Ao-Elvw$_2$-EBtw$_2$-Btw$_2$-BCnw$_2$

- At, 0-4 cm, dusty sandy loam, gray, small polyhedral structure,
- Ao, 4-33 cm, dusty sandy loam, greyish brown, medium polyhedral structure,
- Elvw$_2$, 33-52 cm, dusty sandy loam, light brown, monogranular structure,
- ABtw$_2$, 52-70 cm, dusty sandy loam, light rusty brown, prismatic structure,
- Btw$_2$, 70-84 cm, dusty sandy loam, brown with rust spots, prismatic structure, very compact
- BCnw$_2$, 84-151 cm, dusty sandy loam (SS), light rust brown, massive, moderately developed

Physics:

- the texture is dusty sandy clay between 0-151 cm;
- very high total porosity between 0-4 cm and medium between 4-52 cm;
- very low apparent density between 0-4 cm and medium between 4-52 cm;
- wilting coefficient small between 0-33 cm and medium between 33-52 cm;

Chemicals:

- moderately acidic soil reaction between 0-151 cm;
- low humus reserve;
- the nitrogen index is low between 0-52 cm.

Table 4 US 4 Analysis Bulletin

Depth	cm	0-4	-33	-52	-70	-84	-151
Granulometric analysis		SS	SS	SS	SS	SS	SS
Coarse sand (2.0 - 0.2 mm)	%	17.1	16.7	15.1	19.8	17.6	15.0
Fine sand (0.2-0.02 mm)	%	31.2	32.3	31.5	29.4	29.3	29.3
Dust (0.02 – 0.002 mm)	%	37.0	36.8	36.1	31.6	33.8	33.8

Depth	**cm**	**0-4**	**-33**	**-52**	**-70**	**-84**	**-151**
Colloidal clay (under 0.002 mm)	%	14.7	14.2	17.3	19.2	19.3	21.9
Physical clay (below 0.01 mm)	%	33.5	33.3	35.9	34.2	35.7	37.8
Specific density (Ds)	g/cm^3	2.6	2.63	2.65			
Apparent density	g/cm^3	1,2	1.45	1.48			
Total porosity (PT)	%	53.85	44.87	44.15			
Aeration porosity (PA)	%	25.65	12.24	11.29			
Grade of subsidence (GT)	%	-10.42	8.09	10.72			
Coef. of hygroscopicity (CH)	%	5.42	5.49	6.40			
Coef. of wilting (CO)	%	8.14	8.24	9.61			
Field capacity (CC)	%	23.5	22.5	22.2			
Total capacity (CT)	%	44.87	30.94	29.83			
Useful water capacity (CU)	%	15.37	14.26	12.60			
pH in water, soil:water ratio 1:2.5	unit.pH	5.28	5.31	5.57	5.48	5.59	5.72
	t°C	24.2	24.3	24.3	24.3	24.3	24.3
Humus	%	2.82	1.80	0.81			
Reserve humus	t/ha	13.54	75.69	14.38			
Mobile phosphorus in Al recalculated by pH	ppm	23.74	23.74				
Mobile potassium in Al	ppm	71	60				
Sum of exchange bases (SB)	me/100 g soil	3.46	4.23	2.50	5.96	6.35	6.15
Exchangeable hydrogen (SH)		8.17	8.32	7.50	6.54	5.82	4.90
Cation exchange capacity (T)		11.63	12.55	10.00	12.50	12.17	11.05
Degree of saturation in bases (V)	%	29.75	33.71	25.00	47.68	52.17	55.66

The ecological characterization indicators were processed as they were written in the physical-geographical or pedological characterization legend table. These indicators refer to soil, relief, groundwater, lithology, climate, hydrology, pollution. All the indicators used (directly or indirectly) for the natural assessment, for the analysis of the limiting and/or restrictive factors and for establishing the requirements and ameliorative measures have been entered in the tables with codes [18].

Depending on the values of the main characteristics determined in the analysis bulletins as well as from the observations made in the field, the codes were established for the 17 indicators used in the calculation of credit scores (Table 5).

Table 5. Pedological indicators codes of soils from Fârdea pastures

U.S.	**Pedological indicators**																		
	3C	**4C**	**14**	**15**	**16**	**23A**	**23B**	**29**	**33**	**38**	**39**	**40**	**44**	**61**	**63**	**69**	**133**	**144**	**181**
1	10,5	575	0	0	0	22	22	0	22	0	15	0	5	1	5,6	65	88	90	1
2	10,5	750	2	0	0	21	11	0	1	0	2	0	15	1	7,0	65	175	90	2
3	10,5	750	3	0	0	32	32	0	1	0	2	0	15	1	6,1	65	175	90	2
4	10,5	650	0	2	0	34	34	0	7	0	15	0	5	1	5,2	20	175	90	1
5	10,5	575	0	2	0	42	52	0	22	0	15	0	15	1	4,7	43	175	90	1
6	10,5	575	0	2	0	32	22	0	22	0	15	0	15	1	4,7	43	175	90	1
7	10,5	650	0	2	0	31	42	0	17	0	15	0	15	1	5,2	65	175	140	1
8	10,5	650	0	2	0	43	42	0	12	0	15	0	15	1	5,2	65	175	90	1

U.S.	Pedological indicators																		
	3C	4C	14	15	16	23A	23B	29	33	38	39	40	44	61	63	69	133	144	181
9	10,5	650	0	3	0	22	22	0	12	0	15	0	15	1	5,6	43	175	90	1
10	10,5	650	0	3	0	42	42	0	12	0	15	0	25	1	5,2	43	175	90	1
11	10,5	575	0	3	0	34	34	0	22	0	15	0	15	1	5,2	43	175	90	1
12	10,5	575	0	0	0	12	12	0	1	0	15	0	5	1	7,0	79	88	140	2
13	10,5	750	0	4	0	33	43	0	1	0	15	0	15	1	5,6	65	175	140	1

Evaluation notes as they result from the calculation have a physical value and express the synthetic capacity of the plants, at a given moment, which in turn are subject to permanent changes and adjustments based on genetic or technological advances.

The calculation of the average production per hectare for each approved plant is based on the credit score given in relation to the technological level that can be ensured at a given time and which establishes the productive capacity on each credit point [18].

In order to estimate the general potential of agricultural land, the tables were created with the classification of land according to current use modes in quality classes in natural regime, establishing the weighted average grades for quality classes, but also for the land used for current use modes (Table 6).

Table 6. Evaluation notes of soils from Fârdea pastures

U.S	Surface (ha)	Use category											
		PS	FN	VV	VM	VI	MR	PR	PN	CV	CS	PC	LI
1	214,47	31	18	39	24	32	36	39	40	40	29	24	39
2	9,00	54	40	51	44	48	58	66	57	58	73	73	64
3	204,67	81	65	46	37	42	53	59	52	47	59	59	56
4	28,16	52	41	65	45	55	66	57	45	66	57	65	58
5	47,49	37	25	23	14	18	33	19	31	36	16	12	30
6	41,69	33	23	23	14	18	29	19	25	33	16	12	26
7	225,72	66	47	65	49	57	58	65	65	58	57	49	62
8	335,01	73	52	66	52	59	66	66	81	66	66	58	70
9	517,46	44	26	41	31	36	47	47	45	47	59	52	50
10	144,05	52	37	42	29	36	47	37	46	47	37	37	44
11	35,88	33	23	33	18	26	30	24	26	33	16	14	28
12	63,21	19	11	43	36	40	41	39	39	45	39	58	44
13	15,82	73	59	40	29	34	51	65	50	51	49	49	54

Regarding the agrochemical characterization of the pastures in UAT Fârdea, we encounter the following situation.

Soil reaction (pH) is moderately acidic, with an average value of 5.63. Analyzing the soil reaction according to the assessment intervals, it appears that the surface of 145.26 ha (7.72 %) has a strongly acidic pH, the surface of 1502.62 ha (79.82 %) has a moderately acidic pH, the surface of 9.03 ha (0.48 %) has a slightly acidic pH, the surface of 190.55 ha (10.12 %) has a neutral pH, and the surface of 35.15 ha (1.87 %) has a slightly alkaline pH.

Doses of amendments are recommended in order to correct the acid reaction, these being between 0.36 and 3.19 tons/ha, resulting in a total amount of 1705,20 tons, which will be applied on the surface of 1406.45 ha.

Phosphorus supply shows average values, the weighted average of the phosphorus content being 28.98 ppm P. Thus, on an area of 178.54 ha (9.48 %), the phosphorus supply is weak, on an area of 1453.92 ha (72.23 %) the phosphorus supply is average, on an area of 158.35 ha (8.41 %) the phosphorus supply is good, and on an area of 91.80 ha (4.88 %) the supply with phosphorus is very good.

The potassium supply of the soils is medium, the potassium content being 89 ppm K. Thus, on an area of 295.58 ha (15.70 %), the provision of potassium is weak, on an area of 1492.47 ha (79, 28 %) potassium provision is medium, on an area of 26.41 ha (1.40 %) potassium provision is good and on an area of 68.15 ha (3.62 %) potassium provision is very good.

Humus reserve is medium, the average being 2.64%. Thus, on the surface of 180.46 ha (9.59 %) the insurance is very weak, on the surface of 419.70 ha (22.29 %) the insurance is weak, on the surface of 524.60 ha (27.87 %) the insurance is medium, on the surface of 564.18 ha (29.97 %) the insurance is good, and on the surface of 193.67 ha (10.29 %) the insurance is very good.

The nitrogen supply through the nitrogen index (IN) is poor, the average being 1.70%. Therefore, on the surface of 423.51 ha (22.50 %) the insurance is very weak, on the surface of 868.18 ha (46.12 %) the insurance is weak, on the surface of 496.36 ha (26.37 %) the insurance is medium, on the area of 47.77 ha (2.54 %) the insurance is good, and on the area of 46.79 ha (2.49 %) the insurance is very good.

4. CONCLUSIONS

In the researched area were identified the following soil types: Regosols (11.39%), Alluviosols (0.48%), Eutricambosols (10.87%) and Luvosols (77.26%).

The limiting factors that influence the quality of the soil cover within the Fârdea cadastral territory are mainly dimensioned by: the soil reaction with low values (8.81% slightly acidic, 67.36% moderately acidic and 17.78% strongly acidic), the slope of the land and the danger of erodibility (11.02% low, 14.35% moderate and 25.26% high), degree of subsidence (58.16% moderately compacted, 17.37% strongly compacted), humus reserve (82.83% small and 15.32% very small) etc.

The soil reaction is moderately acidic, the average pH value being 5.63. The doses of amendments are between 0.36 and 3.19 tons/ha. The phosphorus supply is medium, the average phosphorus content is 28.98 ppm P. The potassium supply is medium, the average potassium content is 89 ppm K. The provision of humus is medium, the weighted average of the content being 2.64%.

Nitrogen supply is poor, with an average of 1.70%.

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MONITORING THE JUST TRANSITION IN JIU VALLEY, ROMANIA

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Abstract: *In the structure of the project management cycle, monitoring is an important step. The paper makes a comparative analysis between program and project monitoring, customizing on the Just Transition Program in Romania and a project within this program that is implemented in the Jiu Valley. In this context, the paper focuses on presenting the evolution of Just Transition initiatives and related EU-funded projects, as well as on the analysis of the administrative structure of the institutions involved in the governance of the transition to climate neutrality in Romania. The Jiu Valley microregion is one of the beneficiaries of the Just Transition in Romania. Jiu Valley was severely affected by the reduction of coal mining activities. The transition from coal mining to a low-carbon energy system has led to high unemployment, migration of young people and adults, poverty and social exclusion. The paper focuses on presenting the evolution of Just Transition initiatives and related EU-funded projects, as well as on analyzing the administrative structure of institutions involved in the governance of the transition to climate neutrality in Romania. Further, the authors openly discuss and perform a detailed analysis of the major challenges regarding monitoring Just Transition activities and possibilities to overcome the identified challenges.*

Key words: *Just Transition, project management, monitoring, monitoring committee, JUSTEM.*

1. INTRODUCTION

The European Commission (EC) committed to climate neutrality by 2050, in accordance with the European Green Deal [1]. As a result of this commitment, European countries are transitioning from fossil fuels to more clean and sustainable options. However, phasing out fossil fuels exploitation activities generated a major negative impact in the regions where the extractive industry was the most prominent one.

The EC focused on minimizing the problems generated by phasing out fossil fuels extractive industry and other polluting industries. These regions will be the subject of industrial processes transformation, aiming a successful energy transition by setting up the Just Transition Mechanism (JTM) as a general solution for all impacted European countries. The EU has made great strides towards creating a thorough and strong policy framework to assist coal-dependent regions whose economies have been based primarily on coal. The Just Transition Mechanism (JTM) is the central component of this framework via its three pillars: the Just Transition Fund, the InvestEU programme and

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the Public Sector Loan Facility [1]. In Romania, the Just Transition Fund has materialized through a Just Transition Programme, which mainly aims to support regions affected by the ecological transition through strategic investments in sustainable development and economic diversification.

Jiu Valley microregion is one of the areas highly dependent on the hard coal mining activities. Once the coal phase-out process started, undesired economic, social and demographic effects evolved from minor concerns to a generalized decline of the region. As a result of the gradual closure of the hard coal exploitations in the Jiu Valley microregion, there is a labor shortage, and the local communities are searching for new avenues for development, such as industrial, recreational, sporting, and environmental tourism. The industrial activities (mining, electricity and heat, textile and auto spare parts manufacturing, water-sewage infrastructure), education, and health sectors are currently the microregion's main active employers.

The JTM set the context for economic revival and potentially motivate the young workers to remain in the region instead of internally or externally migrating in more prosperous regions of Romania/other countries.

In this context, the paper presents through its theoretical component three aspects: What is monitoring in the just transition mechanism, compared to what are the differences between monitoring in a project and monitoring in a program and as an applicative part aims to provide an overview of the Just Transition

Mechanism for the Jiu Valley microregion and the challenges posed by monitoring the implementation of the JTM by customizing on the JUSTEM project.

2. THE JUST TRANSITION IN JIU VALLEY MICROREGION

In the literature [2,3] the stages of project management are:

- Project Initiation – defining the project's goals and objectives;
- Project Planning – outlining the steps required to meet the objectives;
- Project Execution – carrying out the project plan;
- Monitoring and Control – tracking progress and making adjustments as needed;
- Project Closure – finalizing and evaluating the project. (figure 1)

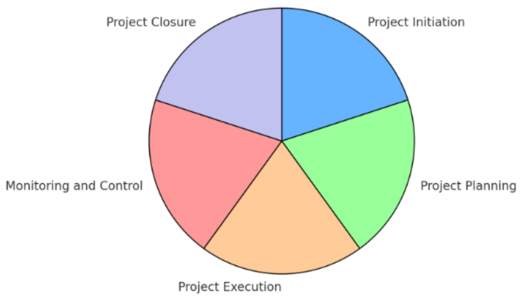

Figure 1. Project management stages

Monitoring in a project and monitoring in a program differ through several components, defined in Table 1.

Table 1. Differences between monitoring in a project and monitoring in a program

The component	Monitoring in a project	Monitoring in a program
1. Purpose	Focuses on a single project with clearly defined objectives, specific deliverables and a fixed deadline. Monitoring focuses on tracking the progress of the project activities to ensure that it meets the required budget, schedule and quality	A program consists of several interconnected projects that contribute to a common long-term goal. Monitoring a program tracks not only the performance of each individual project, but also how the projects interact and contribute to the overall goal of the program
2. Scope	It is more limited in scope, targeting a well-defined set of activities and outputs. The monitored indicators are strictly related to the success of the project itself	It is broader as it involves tracking several projects simultaneously and assessing their cumulative impact. This includes not only the success of each project, but also the synergies between them
3. Focus	Focuses on the short or medium term, tracking immediate results and compliance with specific project planning. Monitoring efforts may include assessing the costs, timing, and risks associated with each project	It is more oriented towards the long term and general strategies, analyzing how the results of each project contribute to the achievement of the wider objectives of the programme. It also tracks how resources are shared and optimized between projects
4. Complexity	Monitoring is relatively simple, focused on a clear set of deliverables, budgets and deadlines	Monitoring is more complex, involving coordination across multiple projects, managing dependencies, and adapting strategy as the schedule progresses
5. Risk management	Focuses on identifying and managing project-specific risks	Includes assessing risks that may affect several projects or the entire program, taking into account the interdependencies between projects

Source: authors

Therefore, it was found that the monitoring of a project is more focused and detailed for a limited set of activities, while the monitoring of a program is more extensive and strategic, having an overview of several projects that contribute to common objectives.

This section presents an overview on the Just Transition Mechanism (JTM) and the translation of JTM specific projects for the Jiu Valley microregion, along with the monitoring process of the Transition in Romania. Further, the authors set the loop on the JUSTEM project.

2.1. The just transition mechanism

The JTM is a strategic pillar of the European Green Deal, enabling local and regional authorities to have an integrated approach to the Just Transition, where all stakeholders and beneficiaries have equal access to all the opportunities created through the Just Transition. To achieve this ambitious endeavor, countries and the EU need to generate numerous investment opportunities. Intensified investment in the regions affected by the phasing-out of the extractive industry activities is the key to expanding employment opportunities by supporting the business expansion of existing companies and establishment of new employers, making sure these workers are moved to more environmentally friendly jobs that also benefit the environment [4].

In the case of Romania, the Just Transition Fund (the financial instrument of the JTM) is aimed at supporting the high number of unemployed persons with medium and basic levels of training/education [5]. They used to work in the mining sector, but currently are unemployed on account of their incapacity of reskilling or upskilling to reintegrate in the labor market [5]. At country level, the ~2 billion euros fund allocation is divided as follows: 72.1% is oriented towards economic policies (retraining, upskilling, investments in/for SMEs and large companies), while the remaining amount (27.8%) is directed to environmental policies[5]. Social policies do not have a planned budget from the Just Transition Fund [5].

Monitoring in the context of the JTM is the process of continuous tracking and evaluation of the implementation of measures and actions intended to support regions and communities affected by the transition to a green and sustainable economy.

The key aspects of monitoring under this mechanism are:

1. Monitoring progress and performance - monitoring assesses how projects and initiatives funded by the JTM are being implemented. This includes measuring progress against set goals, such as:

- Creating new jobs in greener industries;
- Retraining of the labor force;
- Economic diversification of the affected regions;
- Reducing carbon emissions and promoting sustainability.

2. Ensuring compliance with transition plans - the JTM involves regional transition plans, detailing how the allocated financial resources will be used to support the necessary changes. Monitoring verifies that the implementation of these plans complies with the established objectives and respects the commitments made by local authorities and governments.

3. Risk management and minimization - in the transition process, there are associated risks, such as job losses, economic or social instability in the affected regions. Monitoring helps identify these risks early and implement corrective measures to minimize them.

4. Transparency and accountability - monitoring provides a platform to ensure transparency in the use of funds and resources. Thus, national and local authorities, as well as citizens, can verify that the transition is being carried out in a fair and efficient

manner. Monitoring also ensures accountability of those involved, periodically assessing progress and reporting results to relevant bodies.

5. Long-term impact assessment - monitoring examines the impact of just transition measures not only in the short term, but also in the long term. This is important to assess whether the transition really supports the sustainable development of regions and ensures that they are not left behind in the decarbonization process.

6. Correcting the course of action - if monitoring shows that certain measures or projects do not have the desired effects or encounter difficulties, the authorities can adjust the course of action to improve efficiency and ensure the achievement of the set objectives.

2.2. JTM in Jiu Valley microregion

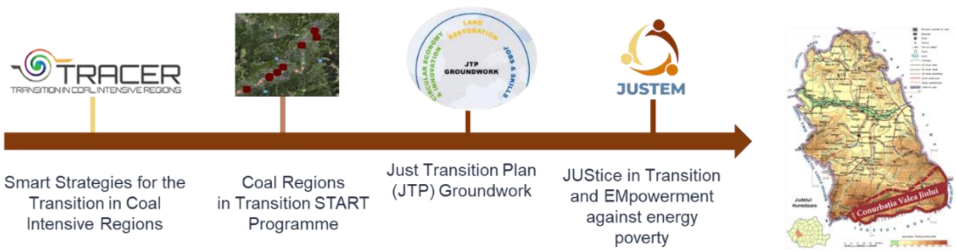

Figure 2. Timeline of Just Transition projects for Jiu Valley microregion

As shown in figure 2, in the past decade Valea Jiului microregion was/is the beneficiary of several projects:

- Transition in Coal Inttensive Regions (acronym TRACER), increasing the capacity of the 4 categories of stakeholders (administration, business environment, academia, civil society), promoting the importance of integrated territorial investments (ITI mechanism), the Energy R&D Strategy of the Area and the steps in its implementation [7]
- Coal Regions in Transition START Programme, in which Technical Secretariat of the European Commission and DG Regio through PwC carried out the Strategy for the Economic, Social and Environmental Development of the Jiu Valley 2022 – 2030 [8]
- JTP GROUNDWORK for technical assistance to support the implementation of Just Transition Plans (one completed in December 2023 and the second started in 2024) [9]
- JUStice in Transition and EMpowerment against energy poverty (acronym JUSTEM) [10]

JUSTEM is an EU funded project started in November 2022 that has the major objective of building regional capacity and adapting regional climate and energy plans to the specific needs of citizens in the regions targeted by the Just Transition Plan. Thus, JUSTEM aims to go beyond simple administrative and technical aspects of implementing Just Transition Territorial Plans and to support regional authorities to "develop and implement plans that are sensitive to local impacts, while engaging citizens in capacity building activities tailored to increase acceptance and build confidence in a coal-free economy.” [10]

3. MONITORING THE JUST TRANSITION IN JIU VALLEY - CHALLENGES

Implementation of the Just Transition needs to be carefully monitored at various levels, to ensure efficient deployment of funding proposals and the impact of the initiatives as compared to the proposals. Therefore, the monitoring activities are adamant for the success of the Just Transition. This section presents the monitoring mechanism in Romania, followed by the main challenges that Jiu Valley is facing with monitoring the Just Transition, particularly in the context of JUSTEM project.

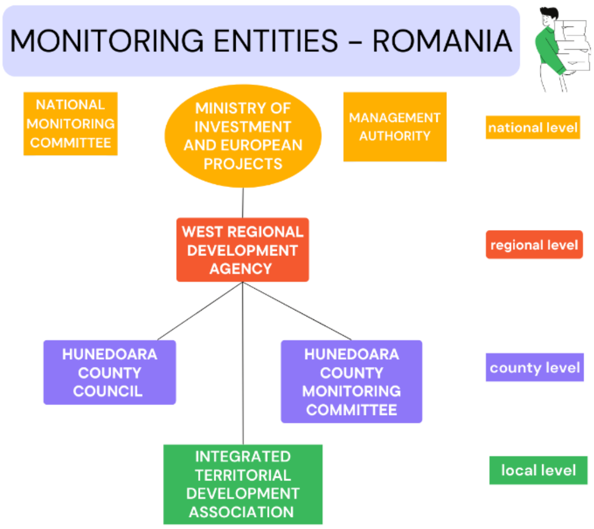

Figure 3. Structural view of the monitoring entities of Just Transition in Romania

3.1. Monitoring entities in Romania

As per figure 3, the monitoring mechanism encompasses several organizations and 6 monitoring committees are involved in the governance of the transition to climate neutrality in Romania, due to its cross-cutting dimension. The process of inter-relational and institutional correlation is adamant for the efficient achievement of Romania's Just Transition objectives.

In Romania, there are eight categories of monitoring entities with responsibilities at national, sectoral, regional or local level: Ministry of Investments and European Projects with the Management Authority and the National Monitoring Committee, West Regional Development Agency as intermediate body, Hunedoara County Council and Hunedoara County Monitoring Committee as county coordinators, and the Integrated Territorial Development Association responsible for the Integrated Territorial Investments mechanism, which endorses the compliance with the Economic, Social and Environmental Development Strategy of the Jiu Valley 2022 - 2030 and the integrated approach to project proposals. The Just Transition Plan was not designed to be the only solution to all the problems specific to each territory negatively affected by the coal phase-out process. The Just Transition Plan aims to integrate the social dimension of the transition process with the ambitious objective of economic reconversion of mono-industrial areas or those dependent on a short value chain.

3.2. Monitoring challenges

As per figure 4, Jiu Valley microregion encounters three categories of challenges in the pursuit of monitoring the Just Transition:

- Over exceeding funding over a brief timeframe, with difficult absorption of funds
- Formalism of Monitoring Committees
- Transparency, accountability and communication challenges derived from the thick, tree organization chart.

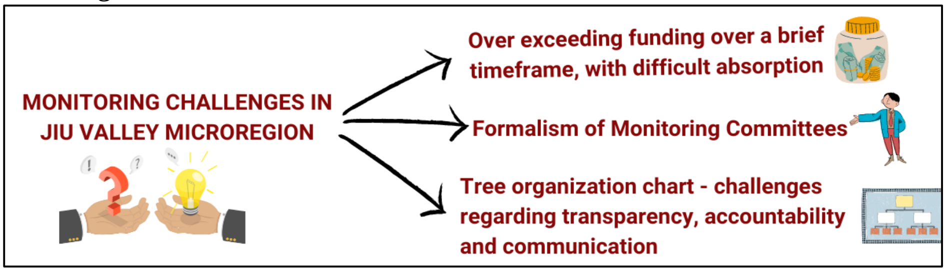

Figure 4. Just Transition monitoring challenges for Jiu Valley microregion

Considering the worrying economic, social and demographic decline of the region in the past decades, the high interest of national and European authorities for restoring and development of the region is completely justified. However, there was a considerable gap between the period when the coal mining phase-out process started, and the rising funding opportunities targeted at compensating the negative effects of the coal mining phase-out. Therefore, the region currently faces a paradoxical situation, where the multitude of funding opportunities overwhelms its potential beneficiaries, who do not always have the know-how and capacity to prepare funding proposals. Also, implementing the awarded proposals can also be challenging for the unexperienced beneficiaries, who lack support and proper training. As of 2023, the Just Transition had a total funding amount of 2.53 billion euro, out of which 525.73 million euro were dedicated to mitigating the socio-economic impact of the transition to climate neutrality in Hunedoara county and 180.9 million euro were allocated for SMEs productive investments (both Hunedoara county overall and Jiu Valley microregion) [11].

Nonetheless, this challenge has been noticed and addressed in the past years. According to the West Development Agency (ADR Vest), Hunedoara County will benefit from 181-million-euro investment opportunities for SMEs. The most recent funding call from this program (due in 20th May 2024), dedicated to the Just Transition in Jiu Valley, was a success: 148 projects were submitted for a total funding of ~441 million euro [12].

Formalism of Monitoring Committees is the second challenge of monitoring the progress of the Just Transition in Jiu Valley. The main causes of this are connected to the fragile institutional structures of the monitoring committees, as well as to their reduced administrative capacity.

Regions with fragile institutional structures deal with high difficulties in efficiently absorbing regional development and cohesion funding [13]. Consolidation of the administrative capacity of regions involved or benefiting from the cohesion policies of EU can be achieved by sorting out the following categories of challenges [13]:

- personnel and organizational management (development of competent and adaptable workforce, attracting and hiring high skilled candidates, orientating long-term learning and development of employees, improved employee involvement, strategic planning of the workforce, adequate organizational structure, improved competency correlation and internal workforce mobility, and improvement of knowledge management and communication flows).
- implementing the strategic program (a more strategic approach to planning, scheduling and setting priorities; improving coordination for conception and implementation of the program, addressing information gaps, improve knowledge sharing and expand communication; effectively strengthen the capacity of beneficiaries; maintain an active relationship with a wide range of external stakeholders; transforming the implementation of processes into more strategic ones; expanding performance measurements to enhance databases and to evaluate results)
- generation of a favorable framework;
- increasing operational innovation of management authorities.

Thirdly, the organizational structure of the Monitoring Committees generates difficulties. The increased centralization and bureaucracy are the results of the tree organizational chart, posing concerns related to transparency. To foster public support and trust, transparency is a basic prerequisite for the dependability and integrity of public institutions [14, 15].

Since citizens can access all information about the work of public administration and are permitted to participate in the decision-making process, the principle of transparency directly affects how accountable the administration is to the people [14, 15]. The thick structure of the monitoring entities leads to reduced accountability of certain employees responsible for sending out documents or official communications. In discussions of public accountability, transparency is mentioned in relation to both performance and deliberation since these are frequently regarded as complimentary forms of accountability [16].

The process of public administration reform is greatly influenced by transparency in public administration, which also raises the bar for effectiveness, responsiveness, and efficiency—three essential elements of the notion of good administration [14].

Another aspect to be considered is the poor communication with interested parties: there were cases when the timeline of sending out an important piece of information was too short for the stakeholders/beneficiaries to react and take action. Official public communication must suffer as long as transparency is compromised [17]. In a time of extreme social, economic, or health crises, inaccurate or unilateral public communication breeds mistrust and creates conditions that are conducive to manipulation and disinformation. [18]. Citizens who have access to information are better able to comprehend public policy decisions and keep an eye on how they are being implemented, which increases public trust in public institutions [19]. According to Androniceanu (2021) public administration entities in Romania have made significant progress in improving transparency, despite that they still struggle with achieving highly transparent practices and communication processes [20].

Without doubt, all interested parties collaborate and investigate the possibilities of reducing these challenges so that transparency and efficient projects implementation becomes the norm in Jiu Valley.

4. CONCLUSIONS

The JTM is the "saving boat" or the "last train" for Jiu Valley region due to the significant investment opportunities oriented towards upskilling and reskilling basic and medium level educated population, as well as improving sustainability practices by implementing specific environmental policies. The most valuable finding of the JUSTEM project is that measures and policies developed under the JTM must consider the needs of the local population and ensure a fair division of the costs and benefits of the change, and successfully address historical socioeconomic, geographic, and environmental injustices as well as current threats faced by the most marginalized and vulnerable groups.

Therefore, monitoring the implementation of JTM initiatives is very important for ensuring the success of the project proposals and their effective implementation. The identified challenges in monitoring the implementation of the JTM must be addressed to minimize the risks posed by a potential improper implementation of the Just Transition in Jiu Valley. The tree organizational structure of the monitoring entities leads to concerns on transparency and public communication with stakeholders and beneficiaries. Furthermore, the high number of funding opportunities can be overwhelming for the beneficiaries, especially when they have limited knowledge on creating and submitting funding proposals. Of course, implementation of the proposals can also lead to further challenges. Furthermore, the formalism of the monitoring committees can be problematic, especially for those entities that should strengthen their administrative capacity.

Monitoring in the just transition mechanism is essential to ensure that the transition to a low-carbon economy is achieved in a fair, efficient and sustainable way, minimizing the negative impact on vulnerable regions and maximizing their economic and social benefits.

All in all, steps have been taken, but there is still room for improvement. The Just Transition Mechanism is deeply valuable for the Jiu Valley microregion development, should the interested parties address completely the above stated challenges in monitoring activities.

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OCCUPATIONAL RISKS EVALUATION FOR THE JOB POSITIONS “MINING ENGINEER" AND "EARTHMOVING MACHINE DRIVER" WITHIN AN ORNAMENTAL ROCKS EXTRACTION AND PROCESSING COMPANY

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Abstract: *The assessment of risks of professional accidents and illnesses is the basic pillar of any effective occupational risk management systematic process. On national level, almost eighteen years have already passed since Law no. 319 on health and safety at work made risk assessment mandatory, but still there is widely applied only one dedicated tool developed and applied for this goal in each company and workplace. Risk assessment involves identifying all risk factors and quantifying their size based on the combination of two parameters: severity and likelihood of the maximum possible consequence on the human body. This article provides the detailed results of an extended specific case study for particular work systems concerning is included alongside results issued for a mining company operating an exploitation of ornamental rocks from the south-east of the country. At the same time, the preventive and protective measures which - based on the risk assessment - were proposed in order to minimize the exposure of workers to the unacceptable consequences identified as potential are highlighted.*

Key words: *occupational health and safety, risk evaluation and assessment, ornamental stone, open pit mining, earth moving machine*

1. INTRODUCTION

Law no. 319/2006 on occupational health and safety contains the following provisions aimed at the obligation of risk assessment [1]:

- the employer has the obligation "to evaluate the risks for the safety and health of the workers, including the choice of work equipment, the substances or chemical preparations used and the arrangement of workplaces" (art. 7, paragraph 4, letter a);
- the employer has the obligation "to carry out and be in possession of a risk assessment for safety and health at work, including for those groups sensitive to specific risks" (art. 12, paragraph 1, letter a)..

Also, by the provisions of art. 13, lit. b, Law no. 319/2006 on safety and health at work establishes the fact that, in order to ensure the conditions of safety and health at work and to prevent work accidents and occupational diseases, employers have the obligation "*to draw up a prevention and protection plan composed of technical*

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measures, sanitary, organizational and other types, based on the risk assessment, to be applied according to the work conditions specific to the unit" [2].

In accordance with Art. 15, para. 1, point 1 of H.G. no. 1425/2006 for the approval of the Methodological Norms for the application of the provisions of the Occupational Health and Safety Law no. 319/2006, the first of the prevention and protection activities carried out within the enterprise and/or unit is represented by "*the identification of hazards and the assessment of risks for each component of the respective work system, work load, means of work/work equipment and the work environment at jobs"* [3], [4], [5].

The method developed by I.N.C.D.P.M. Bucharest is part of the category of analytical, semi-quantitative methods and consists, in essence, in the identification of all risk factors in the analyzed system (workplace) with the help of predefined checklists and the quantification of the size of the risk for each individual risk factor, based on the combination of severity and frequency of the maximum foreseeable consequence [6]. The global risk level, at the workplace, is determined as a weighted average of the partial risk levels, so that the compensations are minimal [7]. The level of safety results indirectly, being inversely proportional to the level of risk[8]. The application of the method is completed with two centralizing documents for each workplace: the risk assessment sheet and the proposed measures sheet [9]. In the first sheet, the identified risk factors, their quantification parameters, the maximum predictable consequence, the severity and frequency classes, the risk level for each individual risk factor and the global risk level at the workplace are entered [10]. The second sheet contains the technical and organizational measures necessary to combat the action of each risk factor at the evaluated workplace, ranked according to the risk levels, starting with the very high levels (7, 6, 5, 4,...). By applying these measures, the workplace moves from a higher risk level to lower levels [11], [12] , [13].

2. DESCRIPTION OF THE INVESTIGATED COMPANY: EXTRACTION AND PROCESSING TECHNOLOGY

VAST NATUR LLC is a limited liability company with its headquarters in Constanța County. The main activity of the company is 0811 – *Extraction of ornamental stone and stone for construction, extraction of calcareous stone, gypsum, chalk and slate, according to codification* (Order 337/2007, Rev. CAEN 2), and the authorized activity is carried out at the secondary headquarters in Baia village, Baia commune. At this headquarters the company is authorized to carry out the activity with CAEN code 2370 - *Stone cutting, shaping and finishing*, respectively the activity of the stone processing factory.

It is a market-oriented but also a profit-oriented organization. The company, established in 2003, belongs to the micro-enterprise category, with an average number of employees 7, a turnover of 282,387.00 lei according to the annual balance sheet. The company is a company established as a result of the business opportunities represented by the demand for natural stone in the construction market and the sophistication of architectural projects over time. The area of Baia commune, Tulcea County, tarla 58, plot 521 and tarla 66, plot 641 offered the answer to this opportunity, ensuring both the raw material - natural stone from Dobrogea, as well as conditions for the development of a factory for cutting, shaping and finishing the stone and its transformation into ornamental and construction stone. Since the company was founded in 2003, it has undergone some legal changes until now, illustrated in table 1.

Table 1. Legal evolution of the work points within the analyzed company

The evolution of the company	
Activity year	**Remarks**
2003	Mention 22419/16.06.2003 - opening of the construction stone extraction branch (1411) and stone processing (2670) in Baia commune, DN 22A, Km 53, Tulcea county
2004	Mention 24118/25.06.2004 – opening of work point Dolphinarium Zone - trade
2005	Mention 23019/16.02.2005 - opening of work point Baia commune, DN 22A, KM 53, Tulcea county CAEN 2670 - trade Mention 40409/17.06.2005 – opening of work point Delfinariu beach area, Constanta - trade Mention 40711/23.06.2005 – opening of work point Mamaia, Camping Popas III Mamaia, Constanta county – trade Mention 237102/19.08.2005 – closure of Mamaia work point, Camping Popas III Mamaia, Constanta county
2007	Mention 28453/02.04.2007 - opening of Constanta work point, Ion Ratiu str. 5A, Constanta county - store presentation and closing of work point Delfinariu beach area, Constanta
2008	Mention 37653/22.05.2008 - opening of work point Sat Camena, Baia commune, T33, P202, Tulcea county CAEN 0811 and closure of work point Constanta, str. Ion Ratiu 5A, county. Constant
2010	Mention 7189/15.02.2010 – correction of material errors deletions SC Vast Natur SRL branch Baia branch, Tulcea county Mention 37571/24.06.2010 - they close: Sat Camena work point, Baia commune, T33, P202, Tulcea county and commune work point. Baia, DN 22A, KM 53, Tulcea county.
2011	Mention 31216/31.05.2011 – extension of validity of work point, Baia commune, Tulcea county
2012	Mention 534217/22.05.2012 – change of the address of the commune work point in: Baia commune. Tarla 58, plot 521, Tulcea county
2013	Mention 45130/28.05.2013 – modification of company administrator data: change of identity card
2014	For the working point of Baia commune, Jud. Tulcea, tarla 58, parcel 521, the loan agreement was authenticated and extended on 01.09.2014 due to the requirements of the program to have at least 3 years of validity and to be authenticated at the notary

The company was established to carry out, mainly, the activities of (1) extraction of ornamental stone and stone for construction, extraction of calcareous stone and (2) cutting, shaping and finishing of ornamental stone, respectively ornamental limestone. Business, financial and marketing efforts are focused on the types of activities mentioned above and on the marketing one, so that they are organized and carried out under attractive conditions for customers - mostly legal entities with activities in the field of construction, but also individuals private companies, as well as stone export partners, subject to compliance with the legislation in force, including safety and health at work, environmental legislation.

Ornamental stone and construction stone extraction activity is carried out in the quarry located in Baia commune, Tulcea county. Exploitation is done on the basis of Concession Agreement no. 3183/2009, concluded with the Baia Municipal Council for a period of 20 years, for an area of 1.55 ha, and the annual permits for limestone exploitation, issued by the National Agency of Mineral Resources, the last permit being number 16625/ 28.08.2013. Reserve consumption is 400 mc/year.

Stratified limestone is mined, through a technological process that includes the manual extraction of limestone, with chisels, wedges, awls and sledgehammers, in slices, following the stratification planes and the fracture planes. The extracted limestone slabs are stored in sortings in the hearth of the quarry, with a view to delivery to the own natural stone processing factory, or to direct beneficiaries. As a result of the extraction activity, the following raw materials result:

- Rough stone for foundations and masonry
- Stone with polygonal contour for paving
- Stone with polygonal contour for veneers
- Valuable technological waste: clays, altered limestone fragments and blocks, dust.

The extraction activity is carried out according to a schedule of 5 days per week, 8 hours per day.

The stone processing activity, namely cutting, shaping and finishing of the stone is focused at the stone processing factory in the same commune, developed in such a way that the entire activity of the company is integrated and covers as much as possible of the value chain of the production of ornamental stone , in the same place and with minimal collateral expenses. The factory is located on a plot of land with an area of 2455 sq.m., and the activity takes place in buildings intended for the production hall, production workshops and a mechanical workshop for the maintenance and repair of the equipment and machinery and warehouses for storage. The factory premises are organized on platforms for the storage of *(1) raw material, (2) finished products and (3) stone waste*. All platforms are concrete built. Also, employees have a changing room (lockers) and sanitary facilities at their disposal. The factory has access to all the utilities necessary for good operation – drinking potable water, waste water assessment and treatment, as well as electricity. The location has direct access to the DN22 national road that connects Constanța with Tulcea.

The ***technological operations*** that ensure the transformation of the stone into ornamental stone products and for constructions include the sorting and selection of the raw stone that respects the dimensions necessary for the introduction into the cutting and shaping process, the cutting and shaping of the stone and its transformation into the stone products manufactured by the applicant with the help of cutting machines. cutting, shaping and finishing that can only process stone fragments up to 15 cm high, palletizing and packaging for delivery to customers.

Through the methods and with the appropriate equipment presented previously, the following specific products are obtained, also illustrated in fig. 1:

- shaped natural stone
- rustic plywood stone
- ornamental stone for gardens
- stone plywood plinth
- paving stone
- rough uncut stone.

The color of processed ornamental limestone is in the range of white, cream, greenish. The cream-white color is considered rare.

Shaped natural stone is intended for interior (interior wall cladding, fireplaces, cellars, etc.) or exterior (facades, wall cladding, stone fences, plinths, walkway paving, gardens, swimming pools, etc.). The shaped stone has a thickness between 3.5 and 14 cm, the length is variable and to order, it can be produced based on the customer's specifications.	
The ***stone for rustic veneer*** is intended for arrangements and decorations made for both traditional and modern looking buildings. It is suitable for cladding facades, fences, exterior walls. It can be mounted with or without joints. Available thicknesses are 2-4 cm and 4-6 cm.	
The ***natural stone corner*** can be put into operation easily, used both in interior design (interior wall cladding, fireplaces, wine cellars, etc.) and exterior (facades, wall cladding, stone fences, plinths, walkway pavements, gardens, swimming pools, etc.). Corners can be between 3.5 and 14 cm thick and variable in length.	

Natural paving stone can be used for paving driveways, terraces, house plinths, fences or for interior ornamental walls. The product has a high mechanical resistance and technical characteristics that ensure it against water absorption. It is processed for thicknesses of 1-3 cm and 3-6 cm.	
Ornamental stone for gardens and ornamental slabs are used for landscaping gardens, artesian fountains, swimming pools and, in general, outdoor spaces.	

Figure 1. Categories of finished products after exploitation-processing

From its foundation until now, the company has had predominantly private clients, as well as legal entities such as: Altdorf Tehnik LLC, Stone Age Construct SRL, Centrul Cocor Spa Neptun, Mara Construct SRL - rehabilitation and restoration of the "Tropaeum Traiani" Adamclisi monument, ABC VAL SRL – Constanta Casino Promenade. The sale of ornamental stone - ornamental limestone, also known as "*Dobrogea stone*" is mostly carried out to legal entities - with direct implications in the construction sector. Started in 2013-2015, the company's future projects include the intensification of export activities to France and the USA. There is a well-defined market in the field of stone extraction and the manufacture of ornamental stone and stone for construction in the region, but Vast Natur SRL has a major competitive advantage, i.e. it extracts high-quality ornamental limestone, called "*Dobrogea Stone*", and the assortment of extracted stone from its own quarry it has shades of white, cream and greenish, cream-white shades being rare.

The staff structure of VAST NATUR LLC is composed of one TESA staff, 2 sales and commercial agents, 1 mining engineer, 1 earthmoving machinery machinist, 1 processing industry workshop manager, 7 unskilled workers for breaking and cutting construction materials.

3. RISK ASSESSMENT FOR "MINER ENGINEER" POSITION

The purpose of the work process is the management and coordination of specific mining activities in the "day-to-day" mining operation..

The components of the evaluated work system are:

A. Means of production: calculation technique; furniture; stationery, supplies; standard forms; company car; personal protective equipment.

B. Work task: upon entering the shift, instructs the personnel participating in the work process; carries out periodic training of subordinate workers; control work fronts; distributes work tasks to subordinate staff; check if the given provisions are met; check if the staff is fit to perform their duties and is not under the influence of alcoholic beverages, in a state of fatigue, etc.; draws up the necessary documentation - the general exploitation program of the quarry; submit the documents to the National Mineral Resources Agency for approval; ensure the safety zone during the displacement works, loading of the demolished material (stones); check the condition of the slopes; ensures the maintenance of the means of production used; respects the occupational health and safety provisions from its own instructions, the I.S.U. rules. and Environmental Protection; responsible for the mining activity and subordinate workers; is responsible for the quality of the activity of subordinate personnel, for the operational flow approved and carried out in the projects in which he is involved (design, implementation, completion).

C. Work environment: the operator/human factor(mining engineer) carries out his activity both outdoors and in the office. The climatic conditions of the geographical area in which the operation is located configure a work environment characterized by low air temperature in the cold and transitional seasons; the high air temperature during the summer, corroborated with the accumulation of thermal energy on the slope of the quarry; conditions of rain, blizzard, frost, fog; the noise level that exceeds the maximum admissible level for drilling operations, manual demolition by mechanical action; the existence of a level of dust (fine dust particles); it should be noted that during perforation, if there are no air currents, the concentration of dust in the atmosphere of the workplace remains at high levels for long periods, sometimes making it impossible or very risky to enter the intervention areas; lighting is natural and artificial (at night); natural ventilation; air currents on the work route; low frequency radiation of the monitor - when processing data on the computer [14].

Applying the tools and the procedure specific to the INCDPM Bucharest method [15], [16], the concrete forms of manifestation of the risks were identified, the severity classes and the probability classes related to each of the identified risks were assigned, and then - using the scale of framing the risk levels, the partial risk levels were set. The results obtained are centralized in Table 2.

The meaning of the notations in table 2 is as follows: *WSE - Work system element; IR - identified risk; RF – risk factor; MC - Maximum consequence; S - Severity; Likelihood; RL - Risk level; WE - Working equipment; OE - Occupational environment; WT - Working task; HF - Human factor; N-negligible; LTI 3-45 – Lost Time Injury from 3 to 45 days; LTI 45-180 – Lost Time Injury from 45 to 180 days; INV I – first degree invalidity; INV II – second degree invalidity; INV III – third degree invalidity; D – death.*

Table 2. Job evaluation sheet "mining engineer"

Company: Vast Natur		***WORKING PLACE RISK ASSESSMENT CARD***	**Number of exposed individuals:** 3			
Unit: Quarry			**Exposure length:** 8 hours/shift			
Work place: Mining Engineer			**Assessment team members:**			
WSE	**IR**	**The concrete form of manifestation of risk factors (description, parameters)**	**MC**	**S**	**L**	**RL**
WE	Mech. RF	**1. Road accident caused by the quality of the road, especially after rain, frost, landslides - travel to home-office by car;**	**D**	**7**	**2**	**4**
		2. Slide of rock fragments from the slope walls;	**D**	**7**	**2**	**4**
		3. Rolling rocks from slopes or accidental loss of balance;	D	7	2	4
		4. Free fall of rock particles, fine particles carried by the air jet when the pneumatic tracks accidentally break;	INV III	4	1	2
		5. Deviation from the normal trajectory of some rock fragments in motion upon contact with thresholds, etc.	**D**	**7**	**2**	**4**
		6. Collapse, accidental collapse of rocks;	**D**	**7**	**6**	**7**
		7. Positioning in the vicinity of the air cylinders of the compressors;	D	7	1	3
		8. Excessive noise during the demolition operation and of the machinery in the quarry;	LTI 45-180	3	1	2
		9. Free fall of incorrectly positioned parts, tools, materials or during manual handling;	LTI 45-180	3	1	2
		10. Direct contact of the epidermis with dangerous surfaces (cutting, stinging).	LTI 3-45	2	6	3
	Thermal RF	11. The lowered temperature of some rocks, portions of ice reached in the cold season;	LTI 3-45	2	5	3
		12. High temperature (hot objects, radiators);	LTI 3-45	2	5	3
	Electric RF	13. Electrocution at the accidental occurrence of step voltage (in the case of accidental damage to some current paths in the quarry);	D	7	1	3
		14. Electrocution by direct or indirect contact;	D	7	1	3
OE	Physical RF	15. High temperature in summer - outdoors;	LTI 3-45	2	5	3
		16. The low temperature to which one is exposed in the open air in winter;	LTI 3-45	2	5	3
		17. High relative air humidity - abundant and long-lasting precipitation, low temperatures;	LTI 3-45	2	5	3

		18. Strong air currents when working outdoors on slopes;	LTI 45-180	3	1	2
		19. Glare: working with the visualization of large areas of snow and ice illuminated by the sun during winter;	LTI 3-45	2	5	3
		20. Natural disasters: lightning, storm, hail, landslides, etc.	D	7	1	3
		21. Powders released following the sanding operation, loading of the demolished material;	LTI 3-45	2	5	3
		22. Special nature of the environment: work in bumpy relief with variable configuration;	LTI 3-45	2	6	3
WT	Inadequate WT content	23. Ordering the execution of operations that are not included in the duties: the execution of repairs, interventions, adjustments to work equipment (operation not foreseen by the work load), ordering the execution of operations in a wrong sequence, etc.	D	7	1	3
	Physical overload	24. Muscular and skeletal system disorders due to the sitting position during work (static effort);	LTI 3-45	2	5	3
		25. Forced or vicious working positions when walking backwards (bent position, leaning backwards, when stacking, etc.), producing diseases of the bone and muscle system;	LTI 3-45	2	1	1
		26. Mental overload due to difficult decisions in a short time in case of special problems when loading and stacking pallets with goods;	LTI 3-45	2	5	3
HF	Wrong actions	27. Fires caused by non-compliance with legal provisions in the PSI field (smoking in non-permitted places).	D	7	1	3
		28. Defective attachment / positioning of pallets on the forks of the forklift and their slipping, overturning during EM operation.	D	7	1	3
		29. Catching, crushing of the limbs during the performance of work tasks - improper use of EM, tools and equipment provided (due to wrong actions of the executor).	LTI 3-45	2	5	3
		30. Improper storage of materials (not securing them against falling, sliding, rolling, overturning).	INV III	4	2	3
		31.. Falling from the same level (by being obstructed by different materials, packaging remnants placed on the access ways, slipping on wet, oily floors or polished surfaces, etc.);	LTI 45-180	3	4	3
	Omissions	**32. Failure to check the technical condition at the beginning of the program, the good functioning and integrity of the work equipment with which they work.**	**D**	**7**	**2**	**4**

The overall risk level of the job is:

$$\mathbf{Nrg\ 1} = \frac{\sum_{i=1}^{32} r_i R_i}{\sum_{i=1}^{32} r_i} = \frac{1(7x7)+5(4x4)+21(3x3)+4(2x2)+1(1x1)}{1x7+5x4+21x3+4x2+1x1} = \frac{335}{99} = 3{,}38$$

Figure 2 graphically summarizes the associated individual risk values and table 3 centralizes the prevention and protection measures necessary to be implemented to reduce the risks located in the field of unacceptability.

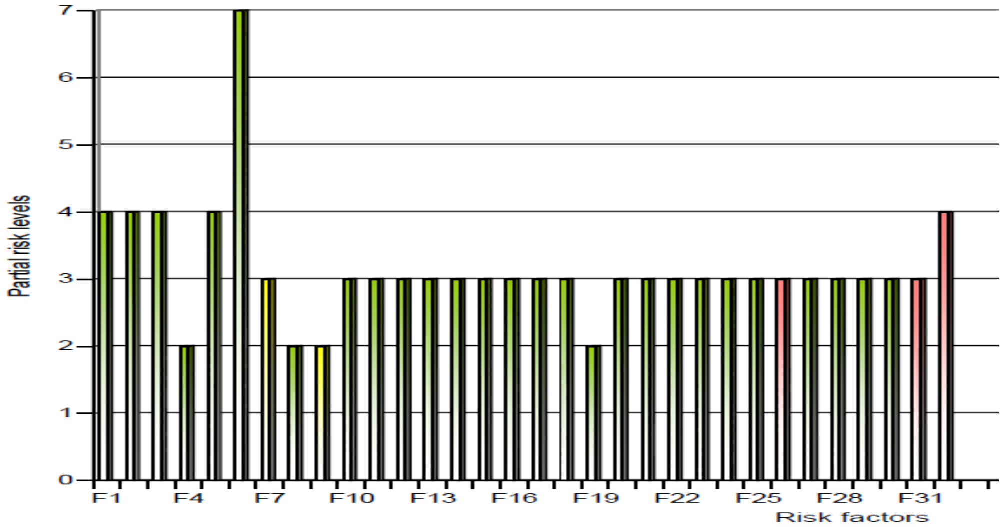

Figure 2. Partial risk levels by risk factors for „Mining Engineer"

Table 3. Proposed action sheet. Job: „Mining engineer"

Risk Factor	RL	Prevention measures
F6: Bursting, collapse, accidental rock fall;	7	***Technical measures*** - The thorough examination of the portions of the rock at risk of falling before the start of work at each shift as well as during work, at least twice a day, especially after rain, thaw, frost. ***Organizational measures*** - Compliance with the monitoring program for the stability of the slopes. - Signaling of places with danger of rolling, tripping, sliding of slopes or rocks. - On slopes with a high work inclination, rock observers will be placed during work with special tasks of observation and warning of the danger of injury due to the fall of the stacked blocks.

F2: Slide of rock fragments from the slope walls ;	4	***Technical measures*** - Consolidation and stabilization of slopes according to the procedures imposed by technology. - Thorough examination of the portions of the rock at risk of falling before starting work in each shift as well as during work, at least twice a day, especially after rain, thaw, frost. ***Organizational measures*** - Compliance with the program for monitoring the stability of slopes. - Signaling of places with danger of rolling, tripping, sliding of slopes or rocks. - Use of PPE and other protective equipment provided.
F1: Road accident caused by the quality of the road, especially after rain, frost, landslides - travel to home-office by car.	4	***Technical measures*** - Consolidation and stabilization of slopes according to the procedures imposed by technology by the road administrators; ***Organizational measures*** - Driving the vehicle at low speed, provided in specific instructions to avoid any dangers related to the quality of the road.
F3: Rock rolling from the slopes;	4	***Technical measures*** - Consolidation and stabilization of slopes according to the procedures imposed by technology. - Thorough examination of the portions of the rock at risk of falling before starting work in each shift as well as during work, at least twice a day, especially after rain, thaw, frost. ***Organizational measures*** - Compliance with the program for monitoring the stability of slopes and slopes. - Signaling of places with danger of rolling, tripping, sliding of slopes or rocks. - Use of PPE and other protective equipment provided.
F5: Deviation from the normal trajectory of some rock fragments in motion upon contact with thresholds, etc.	4	***Organizational measures*** - Compliance with the program for monitoring the stability of slopes. - Signaling of places with danger of rolling, tripping, sliding of slopes or rocks; - Prohibition of simultaneous work on generators by several employees at different rates.

The global risk level calculated for the job "***mining engineer***" is equal to 3.38, which places it in the category of jobs with an acceptable risk level. The result is supported by the "***Assessment Sheet***", from which it can be seen that out of the total of 32 identified risk factors (Fig. 3.1.), 5 exceed, as a partial level of risk, the value of 4; 1 risk factor falling into the category of maximum risk factors, 4 falling into the category of medium risk factors and the other 27 falling into the category of low risk factors and 1 falling into the category of minimum risk factors. To reduce or eliminate the 5 risk factors (which are in the unacceptable range), the generic measures presented in the "Proposed measures sheet" for the workplace are necessary. Regarding the distribution of risk factors by generating sources, the situation is as follows (see fig. 3):

- 48.38% factors specific to the work equipments;
- 25.81% factors specific to the work environment;
- 9.68%, factors specific to the work task;
- 16.13%, human errors.

From the analysis of the Evaluation Form, it is found that 48.39% of the identified risk factors can have irreversible consequences on the performer (DEATH or DISABILITY).

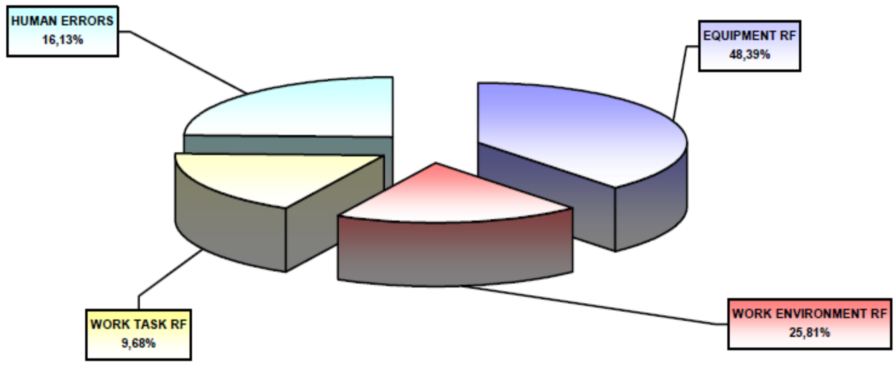

Figure 3. The share of risk factors identified by the elements of the work system. Job - "Mining Engineer"

4. JOB RISK ASSESSMENT: EARTH MOVING MACHINE DRIVER

The operator drives, maintains and supervises aggregates and machines intended for the execution of earthworks, the components of the evaluated work system being:

A. Work equipments: Loader with rear inverted bucket (earthmoving equipment); Intervention and repair tools; Toolbox; First aid kit; Reflective triangles; Travel routes; Fuels (diesel); Lubricants (engine oil, transmission oil, hydraulic oil, greases); Antifreeze (toxic); Freon (in air conditioning systems); Brake fluid (toxic); Accumulator battery electrolyte (H2SO4 solution); Liquid for cleaning windshields; Suspension devices (mechanical and hydraulic); Riding feathers; Manometers for checking tire pressure; Fire extinguishers; Individual protective equipment (coveralls, earmuffs, helmet, gloves, dust mask, protective glasses, protective shoes (boots with metallic pumps), reflective vest.

B. Work task: Excavator driving is based on training and knowledge verification; The driver of the equipment is obliged before starting work to check the technical condition of the equipment, to check whether the warning and warning systems are in working order; During the entire period of travel to the work point, he will respect the traffic rules; Fixing the machine in order to start work will be done according to the own instructions and the provisions of the machine's technical book (level ground, distance from the work point, existing obstacles near the work point, etc.); The operation of the machine will be done with particular care, avoiding its overload; The presence of persons in the area of action of the machine is prohibited; At the end of the work or whenever the driver leaves the machine, he will secure it against accidental movement or use by unauthorized persons; The executor participates in all safety and health at work trainings, respects his own safety and health at work instructions and the legislation in force.

C. Work environment: the activity takes place in the cabin of the machine but also in the open air - atmospheric weather, with permanent noise generated by the operation of the machine as well as pneumoconiogenic powders (dust) released when the material is unloaded in the means of transport (dumpers).

The results of risk identification and assessment are centralized in table 4.

Table 4. Job evaluation sheet "Earth moving machine machinist"

Company: Vast Natur		***WORKING PLACE RISK ASSESSMENT CARD***	**Number of exposed individuals:** 3			
Unit: Quarry			**Exposure length:** 8 hours/shift			
Work place: Earth moving machine driver			**Assessment team members:**			
WSE	**IR**	**The concrete form of manifestation of risk factors (description, parameters)**	**MC**	**S**	**L**	**RL**
WE	Mech. RF	**1. Catching, crushing of upper limbs during interventions with the bulldozer in operation ;**	INV III	4	3	4
		2. Transporting people in the cabin, on the stairs, on the sides of the machine;	INV III	7	1	3
		3. Falling and overturning of technical equipment caused by not securing it or exploitation in improper conditions (bumps, high inclination, overload);	D	7	2	4
		4. Crushing persons in the area of action of the machines caused by improper handling of the machine or the tippers in which the material is loaded;	D	7	1	3
		5. Noise during machine operation;	D	7	1	3

		6. Crushing, hitting moving technical equipment or during interventions (especially when repairing the lower part of the backhoe blade, falling suspended bucket);	D	7	2	4
		7. Slips, falls when getting on/off the technical equipment;	LTI 3 – 45	3	3	3
	Electric RF	8. Electrocution by direct or indirect contact with electric EM;	D	7	1	3
OE	Phisical RF	9. Seasonal climatic variations-weather;	LTI 45 – 180	3	5	3
		10. Noise during machine operation;	LTI 45 – 180	3	5	4
		11. Natural disasters - earthquakes, floods, lightning;	D	7	1	3
WT	Inadequate WT content	**12. Accidental communications during movement, when unloading the material from the bucket, interventions on the machine (grabber bucket);**	D	7	2	4
		13. Muscular and skeletal system disorders due to the seated or orthostatic position during work - static effort.	LTI 3 – 45	2	5	3
	Physical overload	14. Muscular and skeletal system disorders due to the execution of material handling operations - dynamic effort.	LTI 3 – 45	2	5	3
HF	Wrong actions	**15. Use of technical equipment without technical review, in improper condition:** • worn tires above the permitted limit, with air pressure below the permitted limit; • without the acoustic and optical signaling system; • faulty or inadequate lighting system; • defective braking system; • steering wheel play above the permitted value.	D	7	2	4
		16. Wrong use of personal protective equipment or serviced work equipment.	D	7	1	3

		17. **Improper maneuvers**: • traveling at high speed, not adapted to the condition of the travel route; • stopping or working on a slope without ensuring stability; • equipment overload; • lack of insurance during exploitation; • improper exploitation.	D	7	2	4
		18. Failure to comply with the Traffic Code on public roads, driving on improper, slippery roads;	D	7	1	3
		19. Carrying out repair work on the equipment without ensuring accident prevention measures and with the help of untrained persons;	D	7	2	4
	Omissions	20. Failure to check the technical condition at the beginning of the program, the good functioning and integrity of the work equipment with which they work.	**D**	7	1	3
		21.Various airborne dusts;	LTI 45 – 180	3	5	4
		22. Carrying out the activity in an inappropriate psycho-physiological state;	D	7	1	3
		23. Failure to use the means of protection from one's own endowment (in accordance with the internal PPE award list, the legal provisions in force or the own safety and health at work instructions) or from the endowment of the serviced work equipment (in accordance with the provisions of the EM technical book).	D	7	1	3

The overall risk level of the job is:

$$N_{rg\,1} = \frac{\sum_{i=1}^{23} r_i R_i}{\sum_{i=1}^{23} r_i} = \frac{0\,(7x7)+0\,(6x6)+0(5x5)+9\,(4x4)+14\,(3x3)+0x2+0\,(1x1)}{0x7+0x6+0x5+9x4+14x3+0x2+0x1} = \frac{270}{78} = 3{,}46$$

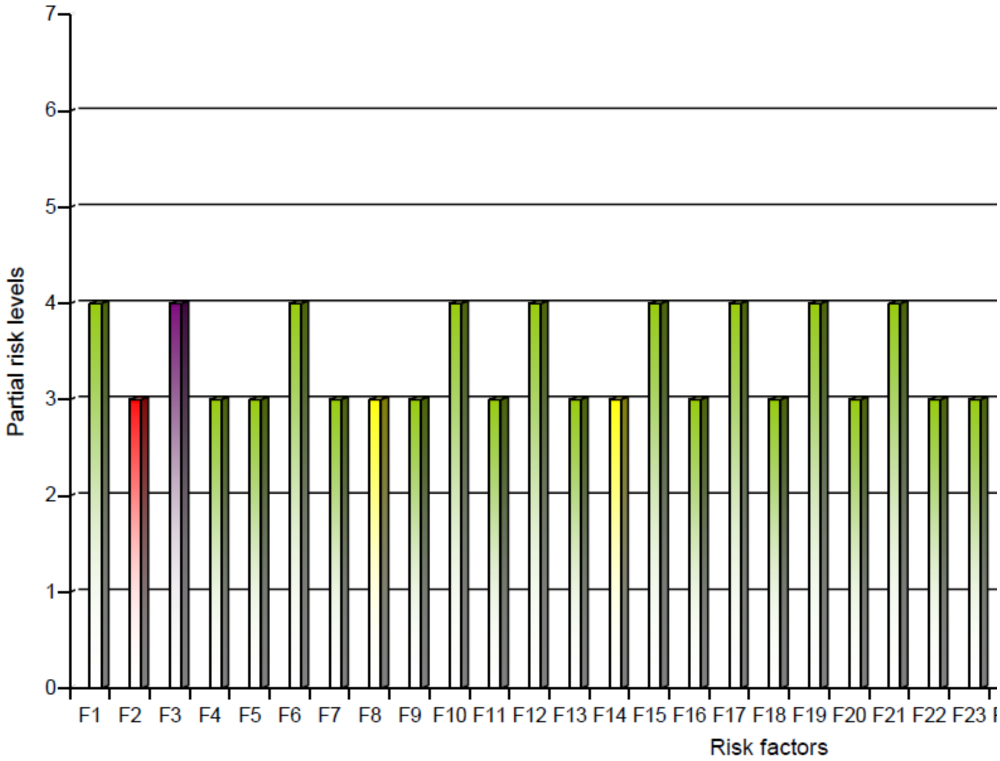

Figure 4. The share of risk factors identified by the elements of the work system
The job "Earth moving machine machinist"

Table 5. Proposed action sheet. Job: „Earth moving machine machinist"

Risk Factor	RL	Prevention measures
F1- Catching, crushing of upper limbs during interventions with the backhoe in operation;	**4**	**Technical measures:** -the technical equipment will be in appropriate technical condition, equipped with all devices for traffic safety (brake, optical, acoustic signaling, lighting system, appropriate tires, etc.); - periodically, based on the schedule and the operating instructions, the technical state of operation will be reviewed, the verification works will be performed only by qualified personnel; **Organisational measures:** - Regular training of employees - own safety and health instructions at work;

F3- Falling and overturning of technical equipment caused by its lack of securing or exploitation in improper conditions (unevenness, high inclination, overload);	**4**	**Technical measures:** - the technical equipment will be in appropriate technical condition, equipped with all devices for traffic safety (brake, optical, acoustic signaling, lighting system, appropriate tires, etc.); - periodically, based on the schedule and operating instructions, the technical state of operation will be reviewed, the verification works will be performed only by qualified personnel; **Organisational measures:** **-** Periodic training of employees in compliance with safety provisions;
F10- Noise during machine operation;	4	**Technical measures:** • work equipment and individual protective equipment suitable for the season and workplace will be given, according to the "Normative framework for granting PPE in force".
F12- Accidental communications during movement, when unloading the material from the bucket, interventions on the machine (grabber bucket);	4	**Technical measures:** - the instructions in the technical book as well as the own safety and health at work instructions will be strictly followed; **Organisational measures:** -the operation of the technical equipment will be done only by trained and authorized persons based on training and knowledge verification, medically fit; - during the periodic training of the personnel in the field of safety and health at work, the dangers that appear due to a decrease in attention when performing repetitive operations and working in an isolated area will be highlighted;
F15 - Use of technical equipment without technical review, in improper condition:	4	**Technical measures:** - the instructions in the technical book as well as the own safety and health at work instructions will be strictly followed; **Organisational measures:** -the operation of the technical equipment will be done only by trained and authorized persons based on training and knowledge verification, medically fit; The schedule will be followed and the technical revisions of the technical equipment will be carried out on time.
F17 - Improper maneuvers;	4	**Technical measures:** - the instructions in the technical book as well as the own safety and health at work instructions will be strictly followed; **Organisational measures:** -the operation of the technical equipment will be done only by trained and authorized persons based on training and knowledge verification, medically fit; - during the periodic training of the personnel in the field of safety and health at work, the dangers of accidents will be highlighted.

F19- The execution of repair works of the equipment without ensuring the measures of accident prevention and with the help of untrained people;	4	**Technical measures:** - the instructions in the technical book as well as the own safety and health at work instructions will be strictly followed; **Organisational measures:** - the operation of the technical equipment will be done only by trained and authorized persons based on training and knowledge verification, medically fit; Training of workers;
F21- Various airborne dusts.;		**Technical measures:** - work equipment and individual protective equipment suitable for the season and workplace will be given, according to the "Regulatory framework for granting PPE in force ".

The global risk level calculated for the job "*Machinist on earthmoving machines*" is equal to 3.46, a value that falls into the category of jobs with an acceptable level of risk because it does not exceed the value of 3.5. The result is supported by the "*Assessment sheet*", from which it can be seen that out of the total of 23 identified risk factors, 9 exceed the value of 4 as a partial level of risk, falling into the category of medium risk factors, and the other 14 falling -are in the category of low risk factors, with a risk value of 3.

In order to reduce or eliminate the 9 risk factors (which are in the unacceptable field), the generic measures presented in the "*Fiche of proposed measures*" for the assessed workplace, are necessary. Regarding the distribution of risk factors on generating sources, the situation is presented as follows:

- 23.07%, factors specific to the means of production;
- 15.38%, factors specific to the work environment;
- 11.54%, factors specific to the workload;
- 30.76%, executor's own factors.

From the analysis of the evaluation sheet, it is found that 51.42% of the identified risk factors can have irreversible consequences on the performer (DEATH or DISABILITY).

3. CONCLUSIONS

The article was developed based on the data provided by S.C. VAST NATUR S.R.L.- Constanța / Tulcea, through job descriptions, lists of technical equipment, their technical books, regulations for granting individual protective equipment, information about technological processes and the development of the work process for each job, received from the company's management and technical staff, as well as their own observations made on the occasion of visits to document and monitor the activity for each workplace.

Proper risk assessment lies at the basis of risk management by business organizations and government authorities. To facilitate the fulfillment of the legal obligations of employers in the field of risk assessment of occupational injury and illness, a relatively large number of methods have been designed and are currently used.

From the multitude of methods used worldwide and nationally for assessing the risks of accidents and occupational diseases, in this paper we chose to use the method developed by the National Institute for Research and Development in Labor Protection “Alexandru Darabont” in Bucharest, Romania. The obtained results allowed the establishment of the acceptability of risks, the prioritization of intervention needs and the prevention and protection measures necessary to minimize the risks of accidents and occupational diseases for the investigated working system.

The method described and illustrated through a case study was approved by the Romanian Ministry of Labor and Social Protection and experimented until now in the industrial field, for more than 6,000 workplaces. Furthermore, based on this method, a significant number of safety practitioners have been trained and authorized as assessors. The process of assessors' training is currently developing.

When applying the risk assessment tool presented, it is imperious to stay focus on the goal of risk ranking. Keeping this in mind, the effect of the subjectivity will decrease and the overall aim will be achieved.

The results of the risk assessment are presented in the "*Job Evaluation Sheet*" and the "*Proposed Measures Sheet*" related to each job analyzed. The full list of evaluated jobs is shown in table 6.

Table 6. The final results of the risk assessment in the analyzed company

No.	**Assessment card no.**	**Job**	**Overall risk level**
1	F 1	Mning engineer	3 ,38
2	F 2	Earth moving machine driver	3 ,46
3	F 3	Sales agent	3, 06

The overall risk level on society is:

$$N_{gS} = \frac{\sum_{i=1}^{3} r_i \cdot N_{gi}}{\sum_{i=1}^{3} r_i} = 3.30$$

The ranking of places, depending on the global level of risk, is shown in the table 7.

Table 7. Hierarchy of work positions according to the global level of risk

No.	**Assessment card no.**	**Job**	**Overall risk level**
1	F 2	Earth moving machine driver	3 ,46
2	F 1	Mning engineer	3 ,38
3	F 3	Sales agent	3, 06

According to the ranking, it is found that all workplaces have a global risk level below the allowed limit (3.5), they fall into the category of those with a low to medium risk level. The value of the aggregate global risk level per company NgS = 3.30, determines its inclusion in the category of those with a low to medium risk level. This situation, good from the point of view of compliance with the legislation in the field of safety and health at work, is due both to the concerns of the designated worker (or the internal/external prevention and protection service) and to the efforts made by the management of the company, which integrates aspects of efficiency economic with those of safety and health at work.

The application of this tool into an enterprise allows:

a. to identify all risk factors at workplaces, operation that is necessary to draw up enterprises own instructions concerning safety at work;
b. ii.to scan the existing situation of each workplace, in such a manner as to ascertain acceptable risks;
c. iii.to ascertain the risk levels at each workplace, as well as their hierarchy;
d. iv.to set priorities regarding prevention measures for each workplace, respectively the optimal utilization of resources assigned for such purpose;
e. v. to set a hierarchy of workplaces from the point of view of hazards and noxiousness;
f. vi.to compare different workplaces as with regard to occupational accident and disease hazards, with applications for the optimal use of economic lever factors;
g. viii. to manage workplace risks with computer-aided techniques, if reliable databases are available.

The tool does possess some advantages, such as accessibility, simplicity in use and is fitted for training/learning the workers basic concepts, such as probability, frequency and gravity, in a qualitative manner. It comes that these methods can be ideal awareness tools for the workers and staff members.

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EXAMINING THE INCORPORATION OF DIGITALIZATION INTO OCCUPATIONAL HEALTH AND SAFETY AND ITS PRACTICALITY: A COMPREHENSIVE ANALYSIS OF EXISTING LITERATURE

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Abstract: *This study examines the digital transformation of occupational health and safety practices, particularly in light of Industry 4.0, with the aim of highlighting their effects on performance, risk reduction and workplace issues. Another aim is to examine the advancements of occupational safety and health (OSH) influenced by digitization and to determine the advantages and disadvantages of integrating digital methods into OSH practices. A detailed literature review was conducted to understand digitalization-related OSH innovations. The paper examined current studies on occupational health and safety and the use of new technologies, finding that digital technologies can significantly reduce workplace accidents. As businesses adopt digital methods, workplace accidents are reduced and performance improved, but new risks are emerging that raise issues of privacy, security, clarity and accountability. While technology affects the workplace to some extent, the digitalization techniques of occupational safety and health must adapt to meet the modern needs of providing health and safety.*

Key words: *Industry 4.0, digitalization, occupational safety and health, safety technologies, digital methods*

1. INTRODUCTION

The COVID-19 pandemic has placed technology at the heart of human life; during the pandemic, technology has been used in all processes ranging from education, health, shopping, and work life, with the aim of protecting and ensuring the continuity of business processes from the outbreak [1]. In this context, digitalization has become a commonly heard concept [2].

Digitalization is one of the most significant technological advances and intervenes in every aspect of life [3]. Besides daily life, it is a phenomenon that restructures many sectors in the business world, changing various service and business models and providing convenience [4].

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The usual development process of work and working conditions has gained momentum with Industry 4.0 and the digital transformation process [1]; industrial models have changed, and the concepts of time and space have disappeared. With massive advancements in internet technologies such as the Internet of Things (IoT), augmented reality, and cloud computing, digital environments have brought the world to the brink of a profound transformation, becoming applications in today's digital world [5]. New technological terms, employment platforms, new professions, different management understandings, and various robotic applications have also entered the digital transformation process [6-8].

After the Covid-19 pandemic, digital transformation is no longer a choice but a necessity [9]. In this regard, the transformation of occupational health and safety (OHS) practices is inevitable [10]. As in many fields of work, the OHS field is affected by technological advancements [11]. Overcoming encountered challenges, reducing costs, and increasing safety require technological developments [12]. Indeed, OHS is very conducive to innovations and technology use [13]. The phrases commonly associated with OHS, such as "wear your helmet" or "wear your gloves," are now replaced by entirely different concepts, and perspectives on OHS are changing [12].

OHS covers processes of identifying risks at workplaces and taking control measures for these risks; it is a proactive and multidisciplinary field [13-15]. The primary goal in OHS is to ensure the safety of both employees and the enterprise [14, 15]. To achieve this goal, Industry 4.0 technologies are used to prevent occupational accidents [16]. However, the digitalization of OHS processes cannot be realized instantly to improve overall OHS performance. Solutions provided by digital OHS technologies, expressed as OHS 4.0, are supports that will enhance and improve the existing activities of organizations [10, 14]. In this context, the benefits of new technologies can be maximized to reduce occupational risks [17].

Digitalization is a renewal process that shows sociological, cultural, and economic change in parallel with technological developments [18]. In simple terms, it is the transfer of an entity or object to the digital environment. For example, it is about transferring all the information and accumulation that businesses have to the digital environment and managing it under new conditions, with new opportunities and problems [19].

The essence of this change and transformation is the ability to perform tasks faster, more effectively, and cheaply thanks to the technological advancements, alongside recording information instantly, processing it very quickly, and using it in decision-making processes [7]. Today, all information and documents that cause time loss and spatial loss, archived in a primitive way in analog systems, have given way to a process that offers digital resources with the help of current technology and tools. Thus, digitalized information and documents have become more easily accessible and shareable, maximizing material and time savings [19].

Another concept that needs to be emphasized after digitalization is digital transformation [20]. Digital transformation is a rapidly evolving process that brings innovations, covering the past, present, and future, and is efficient [22]. It is continuous and dynamic [23].

Research plays a critical role in understanding the implications and ramifications of large-scale phenomena, such as the digital transformation resulting from the COVID-19 pandemic. In the context of this study, the research sheds light on how digital transformation impacts occupational health and safety, thus assisting stakeholders in preparing and adjusting for the evolving landscape of the work environment. The research's value extends beyond mere observation, enabling proactive strategies to maximize the benefits and mitigate the risks associated with digital transformation [21].

2. LITERATURE RESEARCH

This study is prepared in the form of a compilation and aims to identify uncertainties, challenges, and risks related to the integration and applicability of digitalization in occupational health and safety, and to provide solutions. To achieve this, articles, theses, reports, and papers published in peer-reviewed scientific journals in English or Turkish between 2018 and 2023 focusing on the topic of "Digitalization and Occupational Health and Safety" have been examined. Databases such as Google Scholar, PUBMED, and YÖK Thesis Center were scanned online within this scope. The research was conducted using keywords such as "Digitalization," "Digital Transformation," "Digital Technologies," "Industry 4.0," "Occupational Health and Safety," "New Technologies in Occupational Safety," "OHS 4.0," and "Digital Solutions in Occupational Accidents." Comprehensive literature review was conducted, titles and abstracts were considered to eliminate similar studies, all relevant sources were read, and additional studies related to the topic were identified by considering the reference lists of the accessed studies.

3. RESULTS

Digital Occupational Health and Safety Technologies: OHS 4.0

OHS 4.0 is a new concept that aims to maximize the harmony between humans and machines by integrating the basic building blocks of Industry 4.0 and digital transformation processes into the field of occupational health and safety [13, 25]. OHS 4.0 technologies are utilized to prevent potential accidents and illnesses, targeting a safer workplace and employee safety. The damages caused by workplace accidents and occupational diseases have not only economic consequences but also institutional and societal impacts. With new technologies and smart devices, digital applications are being developed to focus on occupational risks, including digital task analysis, dynamic risk assessment, real-time monitoring of employees, and protection against unauthorized access [14, 26]. Additionally, digital technologies bring opportunities such as labor market access for vulnerable groups of workers [17]. The components of digital occupational health and safety technologies within the scope of OHS 4.0 are discussed below [10, 13, 25].

Internet of Things (IoT)

IoT is the way devices interact with each other over the internet, mostly wirelessly. Through IoT, various information is shared in real-time between devices and can be controlled remotely [23]. IoT enables real-time observations and events to be directly recorded in an OHS management system and online OHS records, providing instant access to information as needed [28]. In the field of OHS, IoT is used especially for personnel tracking. For instance, in coal mining, personnel tracking with IoT allows for real-time location identification during accidents, enabling rapid response and access [13]. Similarly, solutions using IoT technology have been developed for tasks such as preventing vehicle/person collisions and collecting data through inactivity sensors for lone workers [10]

IoT Components

Radiofrequency Identification (RFID)

RFID, a component of IoT technology, is used to identify living beings and objects using radio waves. It prevents unauthorized equipment usage and unauthorized actions by individuals, in addition to preventing collisions or falls that workers may encounter in the workplace [15, 26].

Real-Time Location System (RTLS)

RTLS enables continuous monitoring and identification of the locations of objects and employees in the workplace, helping to prevent risks and accidents by ensuring that equipment and workers are where they are supposed to be [14, 15].

Augmented Reality (AR)

Augmented reality combines computer-generated data such as sound and graphics with the physical environment, creating an enhanced perception that blends with the real world [30]. AR applications have ushered in an innovative era in OHS training, removing many constraints such as physical locations and equipment. AR allows for activities that are difficult to simulate theoretically, such as emergency response, case analysis, fire training, and working at heights, to be conveyed to employees in a virtual environment for improved performance [10, 13]. For example, workers can practice and visually learn the workings of machines without direct interaction, thus reducing risk levels. This way, risks can be experienced beforehand, creating a safer working environment and saving time and costs in terms of training and safety [15, 17].

Artificial Intelligence (AI)-Enhanced Security Systems

Artificial intelligence is a computer program designed to acquire information similar to human cognition [26]. The interaction among robotic systems is made possible through AI [25]. Many technologies are used in conjunction with AI algorithms and are being continuously improved. For instance, AI-powered image processing technology allows camera images to be processed based on the requested content, enabling early warnings and proactive measures. Software placed in cameras can trigger alert systems when flame images are detected, aiding in fire detection [10]. Furthermore, digital AI technologies allow real-time analysis of workers using mobile devices, wearable technologies, and personal protective equipment (PPE), both within and outside the workplace. While transparency with data is crucial when using these systems, they offer opportunities to enhance OHS audits, support evidence-based prevention, and increase audit efficiency when used correctly [17, 24]. Microsoft's AI-powered safety monitoring system tracks employees and their activities, vehicle and equipment usage in real-time, detects risks in hazardous areas, and alerts authorized personnel. This software aims to maximize workplace safety and prevent work accidents [16].

Cloud Computing

Cloud computing is a computing system that enables shared information sharing over the internet, rather than using device memory [24]. Technologies like big data and IoT are realized through cloud computing [25], and training programs can also be based on cloud computing [21]. With data from wearable devices transmitted to the cloud, all employees can be alerted in case of potential accidents, enabling instant intervention. All data is recorded to prevent future risks, and sensor data from tags is transferred to the cloud data system for storage and processing. This allows for visualization of results and presentation to authorized personnel. This system allows rapid resolution of incidents and reduction of accident rates [15].

Big Data Analysis

Big data is a technology model that can analyze complex data sets using advanced algorithms and high technology [18]. It enables data to be analyzed at an advanced level compared to traditional tools and can process and combine data from different systems, databases, or websites even if they are not compatible [35]. Big data analysis is significant in terms of OHS as it provides opportunities such as measurement, prediction, goal setting, decision support in OHS, planning the future, and determining action plans [10, 25, 26].

Smart Robot Usage

The use of robotics will be revolutionary in fields such as mining/tunneling, underwater/closed-space operations, or hazardous tasks involving human lives. Particularly, autonomous robots with programmable intelligence can communicate with each other, conduct analyses without the need for an operator, and perform various tasks [25]. Smart robots improve the quality of work and keep employees away from hazards by working in collaboration with humans, enhancing efficiency. For example, drones with camera systems can minimize the risk of falls from heights during inspections, and applications for tasks like lifting heavy objects are expanding with autonomous robots [10].

4. RISKS ASSOCIATED WITH DIGITAL OCCUPATIONAL HEALTH AND SAFETY APPLICATIONS AND EMERGING RISKS

Digitalization brings about unexpected hazards that require new solutions and approaches, while also amplifying existing hazards [22]. In this context, OHS risks will evolve. New working styles that accompany new technologies can lead to safety and ethical concerns. Monitoring technologies can induce stress and anxiety due to concerns about privacy violations. Especially in terms of OHS risks, factors such as performance pressure affecting mental health, reduced social interactions, prolonged working without breaks leading to musculoskeletal issues, and cardiovascular diseases can arise [17, 22]. Remote work requires significant responsibilities for OHS professionals, and it should not be forgotten that remote workers may require more frequent monitoring and support [26]. Furthermore, adjustments to regulations related to changing risk factors [13], continuous monitoring of these risk factors by employers, and seeking solutions for emerging risks are essential [19].

5. EFFECTS OF DIGITAL OCCUPATIONAL HEALTH AND SAFETY APPLICATIONS ON WORK LIFE AND EMPLOYEES

With digital technologies, the requirement for physical presence at the workplace is diminishing [20]. Flexible working arrangements are being adopted, allowing data to be archived on digital platforms and mobile communication resources are always accessible. As a result, remote and flexible work styles such as working from home are becoming increasingly common [4]. Consequently, the number of employees in offices is expected to increase, leading to a rise in workplace accidents and occupational diseases. Thus, occupational health and safety measures need to be applied in office settings that function as workplaces. The increasing number of people working from home may also raise discussions about what kind of OHS measures employees should take in their homes [25].

6. EFFECTS OF DIGITAL OHS APPLICATIONS ON EMPLOYEES

Positive Effects

Digital OHS technologies' monitoring of employees is seen as a significant advancement in preventing potential accidents. For instance, augmented reality applications can provide information and experience to employees about how to act in hazardous situations, and technologies like big data and IoT can analyze information rapidly to prevent numerous potential risks and diseases [14]. Moreover, by utilizing robots and exoskeletons for manual tasks, especially older and disabled employees can continue their tasks with reduced physical effort. Additionally, diseases resulting from sedentary lifestyles and situations like traffic accidents that remote workers might face can be prevented [25].

Negative Effects

The rapid pace of technological change requires employees to learn quickly and continuously. Not only do employees need to know how to use technology, but they also need to possess the relevant skills for new work methods. Changing work models and job nature could mean workers have more responsibility for their own learning and training needs. Smart robots constantly learning might pressure employees to keep up with the pace and level of work, leading to a high level of performance pressure. Furthermore, AI-supported digital monitoring technologies can cause stress and feelings of insecurity, negatively impacting employees' mental health [17, 20, 24]. Overreliance on robots or exoskeletons for manual tasks can lead to reduced physical fitness, resulting in muscle, bone, or joint loss [26]. Additionally, prolonged screen time is believed to cause certain occupational diseases, particularly affecting the eyes. Moreover, psychological ailments like stress, often referred to as the "disease of our time," are likely to become more widespread [24]. According to research by the European Foundation for the Improvement of Living and Working Conditions and the International Labour Organization in 2017, remote workers experience not only increased stress levels but also blurred lines between free time and work hours [20].

7. CONCLUSION

In conclusion, digitization offers both opportunities and new challenges in the field of occupational health and safety. These challenges range from inadequate regulations to unsafe employee behaviors and the shortcomings in adapting to technology. However, various solutions are available to overcome these challenges. Managing digitization within an ethical framework, providing education and involvement for employees, and implementing regulations that enhance safety are key steps in transitioning occupational health and safety to the digital age. This process requires collaboration across a wide spectrum of expertise, from engineers to psychologists, occupational health specialists to designers. Organizations like the European Agency for Safety and Health at Work (EU-OSHA) also contribute significantly to this area. Therefore, it is evident that a continuous effort is essential to guide the transformation brought by digitization in the safest and healthiest manner possible

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NOTIONS REGARDING THE DESIGN AND DIMENSION OF A PARTIAL VENTILATION INSTALLATION - CASE STUDY -

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Abstract: *The problem of industrial ventilation has arisen as a result of serious pollution problems that occur both in the environment of industrial areas and industrial premises. Before addressing an industrial ventilation study, the question must be asked whether there is no simpler means of reducing or eliminating the causes of pollution or reducing pollution by changing the production process or the way the actual ventilation system is designed and built. The commissioning of an industrial ventilation system occurs whenever noxious substances occur in a workplace, in order to maintain a safe, healthy, productive and comfortable indoor environment in conditions of occupational hygiene, safety and health of workers. where this need is determined not only by the degree of human occupation but also, most often, by other factors, for example - production processes.*

Key words: *industrial ventilation, installation*

1. INTRODUCTION

In order to ensure an optimal working environment of comfort and safety of the personnel working in a mining work for opening (preparation) of a layer, it is necessary to dimension the partial ventilation installation (column) in accordance with the Occupational Safety and Health Regulation, chapter " Specific requirements for partial ventilation ”.

This paper deals with some defining elements for a partial ventilation project: the air flow required at the work front, the final length of the work, aerodynamic resistances, the unit coefficient of air losses, the diameter of the ventilation column and the choice of fan.

The partial ventilation that ensures the circulation of air from the entrance to the mining work to the work front, through the columns of tubes on which one or more fans are placed, is achieved through the following systems: discharge, suction and combined. In the paper we will address the discharge ventilation system.

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2. DETERMINATION OF FUNCTIONAL PARAMETERS RELATED TO PARTIAL VENTILATION FANS

For the calculation of functional parameters (air flow Q_v and pressure h_v) must be known to a fan that provides air circulation to the work front:

- the required air flow in the work front, Q_{fp} (m^3/s);
- length of the work L (m);
- diameter of the tube column, d (mm);
- unit aerodynamic drag R_0, ($daPa \times s^2 / m^6$) / m;
- unit coefficient of air losses due to column leaks K_0, $m^3/s/m$.

If the ventilation columns are perfectly tight, then the required air flow to the fan Q_v would be equal to the air flow from the work front Q_{fp}, and the pressure that the fan should develop could be calculated with the relationship:

$h_V = L \times R_0 \times Q_{fp}^2$ (daPa) (2.1)

In reality, however, the ventilation columns, as previously mentioned, cannot be sealed, which is why the size of the air flow to the fan and implicitly the pressure will be affected by the air losses..

In this case, the calculation of the parameters related to the fans is based on the dependence established between the aerodynamic characteristics of the ventilation columns and the ratio of the air flows developed by the fans, respectively the air flows conveyed in the working fronts. According to this dependency, the necessary parameters for choosing the fans can be calculated using the relationships:

$Q_v = Q_R \times Q_{fp}$ (m^3/s) (2.2)

$h_v = R_c \times Q_m^2$ (daPa) (2.3)

in which:

$Q_R = Q_1 / Q_2 = 1{,}02 + 0{,}585\, K_c \sqrt{R_c} + 0{,}15\, K_c^2\, R_c$ (2.4)

where:

$Q_1 = Q_V$ is the required air flow to the fan, m^3/s;

$Q_2 = Q_{fp}$ is the air flow required at the work front, m^3/s;

R_c – aerodynamic strength of the ventilation column, daPa s^2/m^6;

$Q_m = (2\, Q_V + 3\, Q_{fp})/5$ (2.5)

Q_m – the air flow required to be conveyed in the ventilation column,m^3/s.

3. CALCULATION STEPS IN THE DESIGN OF A PARTIAL VENTILATION INSTALLATION

For the design of a partial ventilation installation, the following calculation steps are required:

a) Determine the required air flow at the work front Q_{fp};

b) The final length of the ventilation column is determined L (m) and its corresponding diameter is adopted d (m).

c) The appropriate values for the unit coefficient of air losses are chosen from the tables due to the leakage of the column K_0 ($m^3/s/m$ la 1 daPa) and for unit aerodynamic drag R_0, (daPa s^2/m^6).

d) Calculate the air loss coefficient of the column of length L (m) and its aerodynamic resistance, respectively:

$K_c = K_0L$ (m^3/s la un daPa) (3.1)

$R_c = R_0L$ (daPa s^2/m^6) (3.2)

e) The air flow ratio is determined $Q_R=Q_v / Q_{fp}$ from his relationship Q_R, depending on the corresponding values of the aerodynamic coefficients K_c şi R_c.

f) Calculate the air flow required to be developed by the fan:

$Q_V = Q_{fp} \times Q_R$ (m^3/s) (3.3)

g) Calculate the average air flow:

$$Q_m = \frac{2Q_1 + 3Q_2}{5} \quad (m^3/s) \tag{3.4}$$

h) Determine the required pressure on the fan:

$h_v = R_c \times Q_m^2$(daPa) (3.5)

i) Choose the appropriate fan type (depending on the parameters hv and Qv and the characteristic curves, respectively based on the L-Q nomograms).

3.1. Calculation example

Design of a partially flared ventilation system with a diameter of 500 mm:
Input data according to fig. 1:

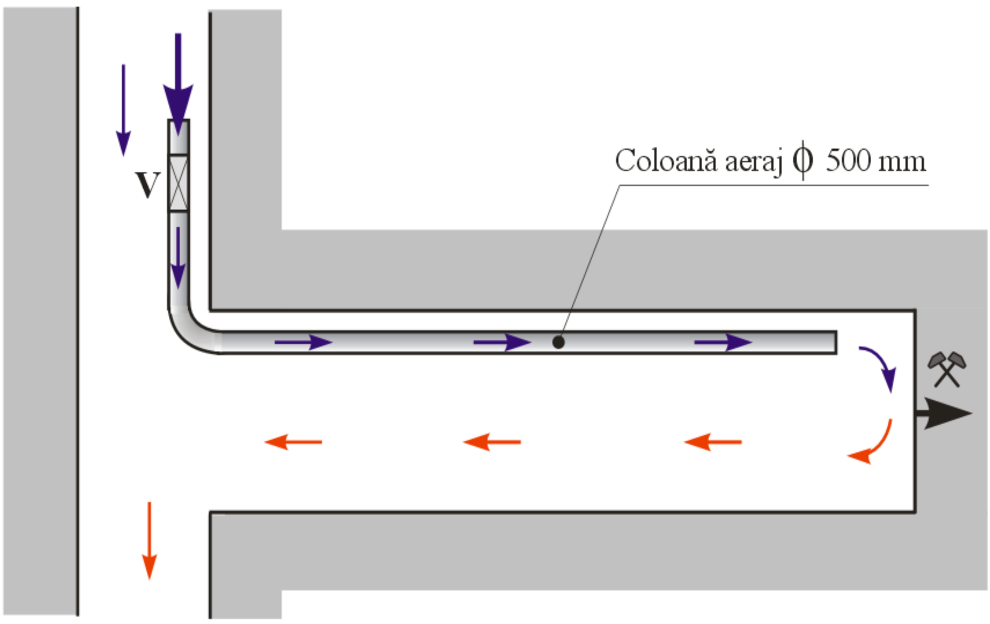

Figure 1. Partly discharge ventilation system

3.1.1. Input data:

$Q_f = 90$ m^3/min = 1,5 m^3/s

L_c = 300 m
Ø = 500 mm
K_0 = 0,0005 $m^3/s/m$ la 1daPa
R_0 = 0,07 daPa s^2/m^7 (Kμ/m)

3.1.2. Calculation of parameters and choice of fan

3.1.2.1. Calculate the air loss coefficient K_c and the aerodynamic resistance R_c for the column of length L (m) with the relations:

$K_C = K_0 \times L$ m^3/s la 1daPa
$K_C = K_0 \times 300 = 0{,}15$ m^3/s la 1daPa
$R_C = R_0 \times L$ daPa s^2/m^6 (Kμ)
$R_C = R_0 \times 300 = 21$ daPa s^2/m^6 (Kμ)

3.1.2.2. The air flow ratio is determined $Q_R = Q_v / Q_{fp}$ with the help of the relationship:

$$Q_R = 1{,}02 + 0{,}585 \times K_C \times \sqrt{R_C} + 0{,}15 \times K_C{}^2 \times R_C$$
$$Q_R = 1{,}02 + 0{,}585 \times 0{,}15 \times \sqrt{21} + 0{,}15 \times 0{,}15^2 \times 21 = 1{,}673$$

3.1.2.3. Calculate the required flow at the fan (Q_v) with the relationship:

$$_R = \frac{Q_V}{Q_f} \text{ m}^3/\text{s}$$
$Q_v = Q_R \times Q_f$ m^3/s
$Q_v = 1{,}673 \times 1{,}5 = 2{,}509$ m^3/s

3.1.2.4. Calculate the average air flow with the relation:

$Q_m = (2 \times Q_v + 3 \times Q_f) / 5$ m^3/s
$Q_m = (2 \times 2{,}509 + 3 \times 1{,}5) / 5 = 1{,}904$ m^3/s

3.1.2.5. Calculate the depression required to move the air, using the relation:

$H_V = R_C \times Q_m{}^2$ daPa
$H_V = 21 \times 1{,}904^2 = 76{,}13$ daPa

3.1.2.6. The necessary parameters are set at the fan:

$Q_V = 2{,}509$ m^3/s
$H_V = 76{,}13$ daPa

3.1.2.7. Choosing the Fan

The parameter-specific nomogram is chosen R_0 și K_0 elected,fig. 3.2 satisfying the aerodynamic parameters specific to the ventilation system..

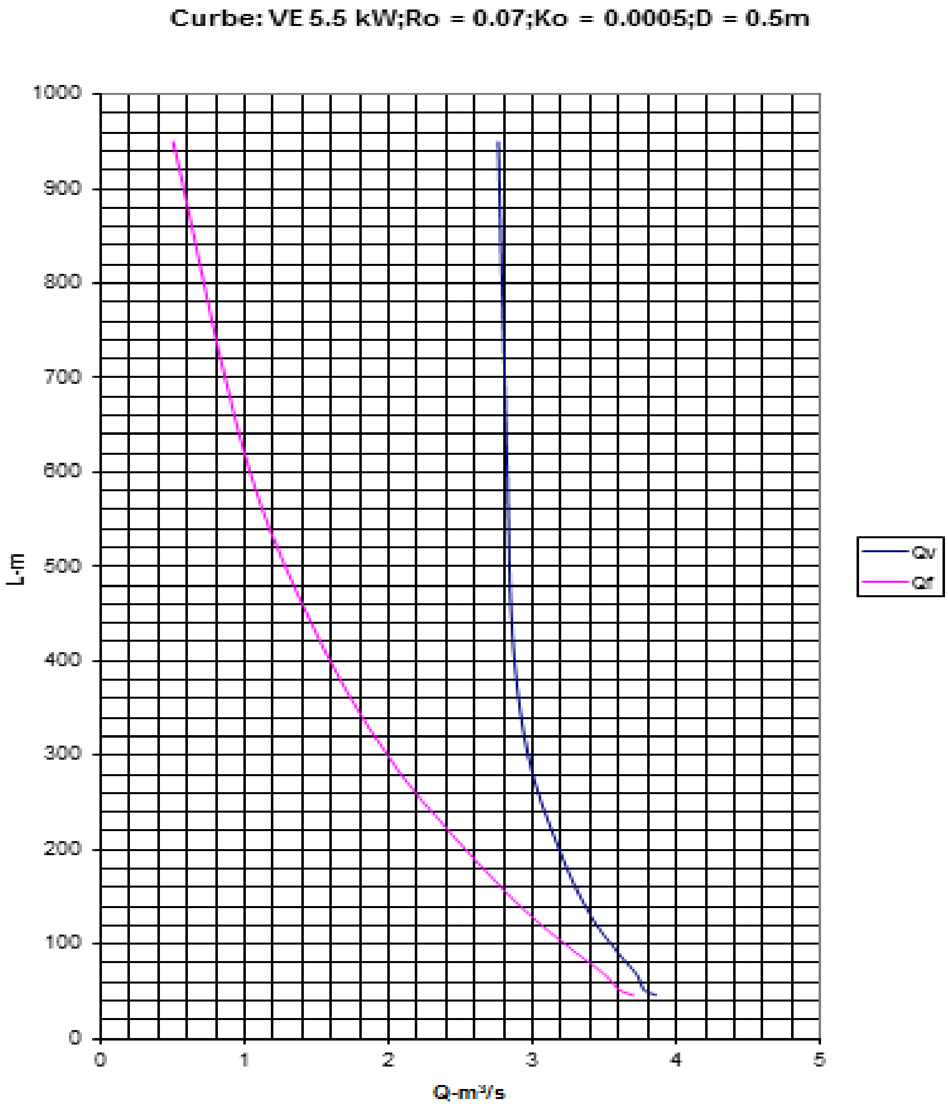

Figure 2. Nomogram VE 5,5 kW

From the nomogram it is easily observed that for R_0 and K_0, the length of the column L respectively Q_f established, it is recommended to use a fan type VEP 5.5 kW.

4. CONCLUSIONS

This paper presents the sizing of a partially discharge ventilation system.

In order to directly choose the fan (s) related to a partial ventilation installation, depending on the required air flow and the length of the column, the nomenclature for dimensioning the partial ventilation installation was elaborated.

From the analysis of the nomogram presented, for an air flow required at the work front of 1,904 m^3 / s, for the ventilation column with a diameter of 500 mm (new columns and very good diameter) the air flow required at the work front can be made with a single 5.5 KW VEP fan.

The use of the nomogram for the dimensioning of the partial ventilation installation allows:

- direct, rational choice of the type of fan required for a given length of mining L and for air flow at the work front, Q_{fp} ;
- establishing the maximum possible ventilation length with a single fan;
- determination of the number of fans and the column length corresponding to each fan.

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CONSIDERATIONS REGARDING THE NEW REQUIREMENTS OF THE CURRENT STANDARDS REGARDING THE EXPLOSION PROTECTION OF EQUIPMENT OPERATING IN ENVIRONMENTS WITH POTENTIALLY EXPLOSIVE ATMOSPHERES

Sorin RASNOVEANU[1], Sorin ZSIDO[1], Diana SĂLĂȘAN[1]

Abstract: *Evaluation of explosion-proof protected electrical equipment in scope of certification is extremely important considering the risk of explosion that has to be minimized in order to ensure life safety and health of workers and to prevent damaging of property and the environment, as well as free movement of goods when they meet the essential safety requirements at European level. The standards SR EN 60079-0 (Explosive atmospheres. Part 0: Equipment. General requirements) and one or more of the standards containing the specific requirements for the type(s) of protection applied to equipment (ex. SR EN 60079-7 for the type of protection increased safety "e"), are used to perform the assessment*.

Key words: *explosive artmospheres, equipment, protection, standards*

1. INTRODUCTION

Explosion hazards can occur in all activities involving gases, vapours, flammable mists or combustible dusts which, when mixed with air, can form an explosive atmosphere.

These can include many of the raw materials, intermediate products, final products and wastes from the normal process of production.

The requirements for prevention and protection of explosions are regulated in specific norms and standards, and a good part of the evaluation of the risk of explosions refers to the evaluation of the conformity of the equipment / installations with the respective requirements [1].

Evaluating the conformity of products with specified requirements is an activity that can be performed by a first, second or third party and can be regulated or unregulated by specific rules and standards.

There are two European Directives, the so-called ATEX Directives, which regulate the placing on the European market of products intended for use in potentially explosive atmospheres (Directive 2014/34/EU) [2] and respectively their safe use (Directive 1999/92/EC).

ATEX is the acronym for "ATmosphere EXplosive"

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An explosive atmosphere is a mixture of flammable substances in the form of gases, vapors, mist or dust with air, under atmospheric conditions in which, after ignition has occurred, combustion spreads throughout the unburned mixture [2,3].

In order for an explosive atmosphere to exist, the flammable substance must be present in certain concentrations.

If the concentration is too low (lean mixture) or too high (rich mixture), no explosion occurs; in fact, a weak combustion reaction may occur, but not a reaction in the whole mixture. Thus, the explosion can only occur in the presence of an ignition source and when the concentration is in the explosive range of the substance, respectively between the lower explosive limit (LEL - lower explosive limit) and the upper explosive limit (UEL - upper explosive limit).

Explosivity limits depend on the pressure and the percentage of oxygen in the air.

The mechanism of producing explosions of gases, vapors or flammable mists/air can be symbolized by the well-known explosion triangle from which it can be seen that the explosion can occur whenever three conditions are met simultaneously:

- the presence of fuel (gases, vapors, dust/powders, combustible mists);
- the presence of the oxidizer (oxygen, oxidizing substances);
- the effective initiation source for ensuring the activation of molecules in order to initiate and propagate the fast combustion reaction.

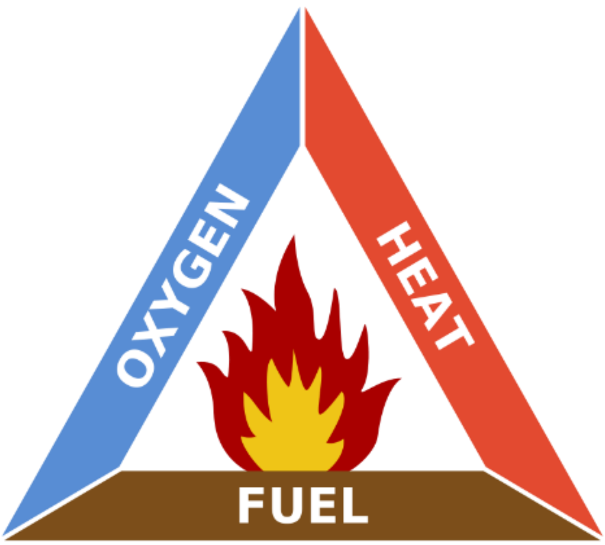

Figure 1. Explosion triangle

Ignition sources and their causes (Ignition source - Cause (example)):

- Hot surfaces - heating devices, mechanical processes caused by friction and cutting, heat loss (clutches and disc brakes).

- Electrical arcs - mechanically generated sparks (e.g. caused by friction, impact or machining processes), sparks of an electrical nature, arcs in electrical switches.
- Flames and hot gases - flames or their hot reaction products such as hot gases and incandescent particles can ignite an explosive atmosphere.
- Mechanically generated sparks - friction, impact or mechanical processing processes such as grinding, tools such as wrenches, pliers or ladders; work carried out on rusted components with aluminum tools (thermite reaction).
- Electrical systems - opening and closing of electrical circuits, equalization of currents, electromagnetic fields, conductive powder.

Note: the low protective voltage is not an explosion protection measure, because ignition is also possible at voltages below 50 V!

- Protection against cathodic corrosion - reverse current to power source, induction, short circuit or ground faults.
- Static electricity - electrostatic discharge.
- Electromagnetic fields - frequency ranges from 9 x 103 to 3 x 1011 Hz. These include high frequency equipment such as radio equipment or high frequency generators.
- Electromagnetic radiation - frequency ranges from 3 x 1011 to 3 x 1015 Hz and wavelengths from 1000 to 0.1 μm. These include optical radiation such as sunlight, lasers, lightning, electric arcs.
- Ionizing radiation - ignition caused by the absorption of energy from short-wavelength UV rays, X-rays, or radioactive materials.
- Ultrasound - ignition caused by absorption of energy from short wavelength UV rays, X-rays or radioactive materials.
- Adiabatic compression and gas flows - due to high temperatures caused by shock waves and cases of adiabatic compression, an explosive atmosphere can ignite.
- Chemical reaction - due to chemical reactions that produce heat (exothermic reactions), materials can heat up and cause an explosion.

2. PRINCIPLES OF EXPLOSION PREVENTION AND EXPLOSION PROTECTION

The need for the coincidence of the explosive atmosphere and an effective ignition source and the anticipated effects of an explosion lead immediately to the basic principles of explosion prevention and protection, in the following order:

a) Prevention: avoiding or reducing explosive atmospheres; this objective can be achieved, mainly, by changing either the concentration of the flammable substance, to a value that is outside the explosion range, or the concentration of oxygen, to a value below the limit oxygen concentration (LOC); - avoiding all possible effective sources of ignition;

b) Protection: stopping the explosion and/or limiting the explosion area to an acceptable extent, through protective measures, for example, through isolation, suppression and constructive limitation. Unlike the two measures described above, here the occurrence of an explosion is accepted.

In most cases where flammable materials are used, it is difficult to guarantee that an explosive gaseous atmosphere will never occur. It can also be difficult to guarantee that the equipment will never generate an ignition source. Therefore, when the presence of an explosive gaseous atmosphere is very likely, the use of equipment with a low probability of generating an ignition source will be resorted to. On the contrary, if the probability of the presence of a gaseous atmosphere is low, it will be possible to use equipment built according to less rigorous standards.

Ex non-mining hazardous areas are classified into zones depending on the probability and duration of the explosive atmosphere (zones 0, 1 and 2 for gases and 20, 21, 22 for combustible dust in the air), and the equipment is divided into categories depending on the level of protection provided by avoiding sources of initiation during normal operation, during foreseeable failures or during rare failures.

The classification of dangerous areas in zones is the responsibility of employers, users of equipment and is regulated by Directive 1999/92/EC transposed in HG 1058/2006, and the classification of equipment into categories corresponding to the level of protection provided is the responsibility of manufacturers, as regulated in the Directive 2014/34/EU transposed in HG 245/2016.

The standards for evaluating the conformity of products with the requirements of the ATEX directive can be technical standards, such as, for example, those for electrical equipment (SR EN 60079-0 general requirements together with the specific standards of protection types) or for non-electrical equipment (SR EN ISO 80079- 36 basic requirements together with the standards specific to the types of protection) or quality standards such as SR EN ISO/CEI 80079-34.

Electrical equipment [2]: equipment containing electrical elements used for the generation, storage, measurement, distribution and conversion of electrical energy, for controlling the operation of other equipment by electrical means or processing materials with the direct application of electrical energy. It should be noted that an assembled final product using both electrical and mechanical elements does not need an assessment as electrical equipment if the combination does not result in additional ignition hazards for the assembly. Non-electrical equipment [4] equipment that can perform its intended function without the use of electricity. In the ATEX Guide, the aspects regarding the consideration of assemblies as products falling within the scope of Directive 2014/34/EU are clarified.

The assembly is defined as a combination of two or more pieces of equipment, together with components if necessary, placed on the market or put into service as a single functional unit.

An installation can be defined as a combination of two or more pieces of equipment that have already been placed on the market independently by one or more manufacturers.

A machine is always considered to be an installation if:

- the end user or the installer purchases component parts (including ATEX components or equipment) from different manufacturers and these are installed under his direct responsibility after a full risk assessment has been carried out;

- the user performs a whole series of different processes that require the integration of ATEX equipment and components in the field and they are installed according to a unique scheme;

- the user grants the construction of some components of his installation outside the land, which may be unique, but are not serial production, and this operation is done under his direct responsibility, or indirectly through a contractor working on a contract basis with him .

- It is necessary to carry out tests or adjustments after the machine is made and these operations must be done under the final responsibility of the end user.

3. THE NEW REGULATIONS IMPOSED BY THE STANDARDS IN FORCE

Explosion-proof characteristics of electrical equipment, are assessed mainly according the provisions of harmonized standards from the SR EN 60079 series. The standards SR EN 60079-0 and one or more of the standards containing the specific requirements for the type(s) of protection applied to equipment (also from the SR EN 60079 series) are used for performing the assessment [5].

In order to be able to work in explicit atmospheres, the equipment must be made and tested according to the specifications described by the standards in force, for each type of protection. Since the standards change quite often, equipment manufacturers and certification bodies must comply with the requirements of the latest version of these standards.

Very important changes regarding the types of protection, were found in the standard applicable to the type of explosion-proof capsular protection (SR EN 60079-1) and to the standard applicable to the type of increased security protection (SR EN 60079-7) [6,7].

According to the SR EN 60079-1 2015 edition standard, information that was not found in the previous edition (SR EN 60079-1 2008 edition), electrical equipment with explosion-proof capsular protection type "d" is included in one of the following protection levels:

- protection level "da" (EPL "Ma" or "Ga");
- protection level "db" (EPL "Mb" or "Gb");
- "dc" protection level (EPL "Gc").

The "yes" protection level is only applicable to catalytic combustion sensors from portable combustible gas detectors.

For the "yes" protection level, the following additional specific requirements must be met:

- the maximum free internal volume must not exceed 5 cm^3;
- the electrical conductors from the sensor must use a sealed joint, directly in the housing wall;
- the sensor breather must be fixed to the housing wall in such a way as to eliminate any interstices (such as cementing or sintering) or it must be pressed into the housing wall with additional mechanical means of fastening (such as embossing);
- powered by a circuit with protection level "ia," with a maximum dissipated power limited to 3.3 W for group I and 1.3 W for group II.

The "dc" protection level is applicable to electrical equipment and Ex components with electrical switching contacts. Their free internal volume must not exceed 20 cm^3 and the devices must be limited to a maximum rating of 690 V d.c. or. that. effective value and 16 A d.c. or a.c. effective value.

All other constructive requirements are applicable for the "db" protection level [6].

With the appearance of a new version of the standard applicable to the increased security type of protection (SR EN 60079-7 2015 edition) and this type of protection has undergone changes. It can be applied to electrical equipment with a nominal supply voltage value that does not exceed 11kV direct current or alternating current effective value for equipment with an "eb" protection level and 15 kV direct current or alternating current effective value for equipment with a level "ec" protection. Additional measures are applied to ensure that the equipment does not produce arcs, sparks, or excessive temperatures in normal operation and under specified fault conditions.

Electrical equipment and Ex components with increased security protection type can fall into the following protection levels: a) "eb" protection level for (EPL Mb or EPL Gb) b) "ec" protection level for (EPL Gc) Level of protection "eb" applies to Ex equipment or components, including their connections, conductors, windings, lamps and batteries; but not including semiconductors or electrolytic capacitors. Protection level "ec" applies to Ex equipment or components, including their connections, conductors, windings, lamps and batteries and also semiconductors or electrolytic capacitors [7].

4. CONCLUSIONS

The new concepts of explosion prevention and protection develop new strategies for preventing the propagation of explosions or limiting the effects of explosions, which requires consideration of aspects related to the closure (limitation, restriction, delimitation, encapsulation) of the explosive mixture.

The purpose of the paper is to highlight the latest changes to the standards. In the paper were revealed the changes of Standard SR EN IEC 60079-1, and the changes of Standard SR EN IEC 60079-7.

To protect people who work in explosive environments, it is important that equipment operating in such areas to comply with the requirements in force, and be properly maintained.

The electrical installations found in hazardous areas have especially designed characteristics in order to operate in such atmospheres. For safety reasons, it is essential that in these area, during the entire lifespan of the installation, the integrity of these special characteristics to be maintained.

According to the requirements in force, in the process of certification of Ex equipment call of them must be tested in order to verify if the explosion protection characteristics are maintained at their level. In this paper was revealed the importance of the changes undergone by the standards. The tests performed on equipment used in potentially explosive atmosphere must be performed according to the requirements of the latest editions of the standards.

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SELECTION OF EQUIPMENT THAT OPERATES IN POTENTIALLY EXPLOSIVE ATMOSPHERES GENERATED BY GASES, VAPORS AND MISTS

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Abstract: *In the European Union (EU), selection of equipment for use in potentially explosive atmospheres is made in accordance with the ATEX (Atmosphères Explosibles) directives. The history of risk management in potentially explosive areas (Ex Zones) is closely related to industrial development and awareness of hazards associated with explosions in flammable environments. Ex classification refers to classification and marking of potentially explosive areas to ensure the correct and safe use of equipment in these environments. This classification is essential for identification and management of explosion risks in various industrial locations. Currently, continuous efforts are being made to improve explosion prevention technologies, safety standards and regulations to ensure a safe working environment in such areas. It is important to note that risk management in Ex areas remains an ongoing concern and the continuous evolution of technologies and regulations reflects the desire to improve safety in these hazardous environments. It is important to pay special attention to selection, installation and maintenance of Ex equipment to ensure a safe working environment in accordance with specific requirements of potentially explosive area. In general, consulting the manufacturer's specifications provides a deeper understanding of equipment's features and capabilities and helps in making informed and relevant decisions regarding its compatibility with the working environment in potentially explosive atmospheres.*

Key words: *selection, equipments, ATEx, Ex zones*

1. INTRODUCTION

The history of risk management in potentially explosive areas (Ex Zones) is closely related to industrial development and awareness of the dangers associated with explosions in flammable environments, [1]. Here is an overview of the evolution of this field:

1. Initial industrial period:

• Since the beginning of Industrial Revolution, use of flammable substances in industrial processes has led to explosion risks. In the absence of proper standards and regulations, incidents were quite common.

2. The 1920s-1930s:

• With the development of chemical and petrochemical industry, the risks associated with handling and processing of flammable substances have become more apparent. However, specific regulations for potentially explosive areas were still in their infancy.

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3. The 1970s:

• Greater awareness has emerged of the importance of risk management in potentially explosive environments. Major incidents, such as the Nypro explosion (1974), led to strengthening of safety standards.

4. ATEX directives:

• In the 1990s and early 2000s, the European Union introduced the ATEX Directives, which set strict requirements for the design, manufacture and use of equipment in potentially explosive atmospheres. These directives were adopted to ensure a uniform and coherent approach at European level.

5. Globalization of standards:

• With globalization of the industry, international standards such as IEC series have been developed and harmonized, which define global requirements for equipment used in such hazardous environments.

6. Education and awareness:

• In recent decades, there has been an increasing emphasis on education and awareness of risks in potentially explosive areas. Companies and safety professionals have become more interested in innovative technologies and solutions to minimize risks.

Currently, continuous efforts are being made to improve explosion prevention technologies, safety standards and regulations to ensure a safe working environment in such areas. It is important to note that risk management in Ex areas remains an ongoing concern and continuous evolution of technologies and regulations reflects the desire to improve safety in these hazardous environments, [2].

2. EX EQUIPMENT

Ex equipment refers to equipment designed and manufactured for use in potentially explosive environments where there is a risk of explosive atmospheres forming. This equipment is built in accordance with specific standards and regulations to minimize the risk of ignition of flammable gases, vapors or dusts in the environment, [3, 4, 5].

Definition of Ex equipment includes a wide range of devices, instruments and machines, such as sensors, measuring instruments, control panels, electric motors, lamps, and more. This equipment must be certified according to relevant standards and their use must be in accordance with specific safety regulations in potentially explosive environments, [6, 7, 8].

Key features of Ex equipment include spark and overheating protection, sealed enclosures, proper cooling systems and other safety measures to reduce risk of explosion in such hazardous environments.

It is important to pay special attention to the selection, installation and maintenance of Ex equipment to ensure a safe working environment in accordance with the specific requirements of potentially explosive area.

• *Category 2*: For Ex zone 1 and 2 areas.
• *Category 3*: For Ex zone 2 areas.

1. Groups of explosive substances:

• Flammable substances are classified into groups according to their properties. For example, group I includes coal mines, and group II is intended for the chemical and petrochemica l industry. Group II is further divided into subgroups (IIA, IIB, IIC) according to their level of danger.

2. Surface temperature:

• Equipment is classified according the maximum surface temperature. This information is crucial to avoid overheating and ignition risks. The classification includes T1 (450°C) to T6 (85°C).

3. Safety markings:

• Equipment intended for use in potentially explosive areas must have specific markings indicating their compliance with Ex standards and ATEX Directive. These include markings such as CE and specific Ex symbols.

3. EQUIPMENT CHOICE CONSIDERATIONS FOR USE IN HAZARDOUS AREAS

Checking compatibility of equipment with the work environment in potentially explosive atmospheres is essential for their safety and effectiveness. Here are some steps you can follow to check compatibility:

1. Consult the manufacturer's specifications: Start by carefully reading technical specifications of equipment provided by manufacturer. They should provide detailed information about the working environment for which the equipment is designed and certified.

2. Hazard area classification review: Determine the exact hazard area classification in which the equipment is to be used. This will help identify the specific requirements for explosion protection in that area.

3. Verification of certification and marking: Ensure that the equipment has the appropriate certifications and markings for the hazardous area in which it is to be used. They should comply with relevant regulations (ATEX Directive) and specific standards.

4. Assess environmental conditions: Consider factors such as temperature, humidity, presence of chemicals and pressure levels in the work environment. The equipment must be designed and constructed to withstand these specific conditions.

5. Analyses operational needs: Consider how the equipment will be used within specific operational processes. Ensure that equipment is adequate for the tasks and operational requirements of work environment.

6. Consult a specialist: If there are doubts or questions about compatibility of equipment with the work environment, consult an industrial safety specialist or an explosion engineer. They can give you advice and recommendations on the right equipment for the specific needs of your work environment.

By considering these issues and consulting information and qualified experts, you can verify the compatibility of equipment with the work environment in potentially explosive atmospheres to ensure a safe and efficient work environment.

Consulting manufacturer's specifications is a crucial step in verifying compatibility of equipment with the working environment in potentially explosive atmospheres for several reasons:

1. Detailed product information: The manufacturer's specifications provide important details about features and capabilities of the equipment. This may include information on operating temperature, pressure levels, chemical compatibility, and other factors critical to the work environment.

2. Certifications and markings: Specifications should include information about certifications and conformity markings of the equipment. This allows you to check that the equipment is suitable for specific hazard area in which it is to be used and complies with relevant safety standards such as ATEX standards.

3. Warranty conditions and proper use: Specifications may provide information about the warranty conditions of equipment and instructions for its proper use and maintenance. It is important to follow manufacturer's recommendations to ensure safe and efficient operation of equipment in the work environment.

4. Compatibility with other equipment: Some specifications may include information about the compatibility of equipment with other equipment or systems in the work environment. This is important to ensure proper integration and smooth functioning of the entire system.

In general, consulting manufacturer's specifications provides a deeper understanding of equipment's features and capabilities and helps making informed decisions regarding its compatibility with the potentially explosive atmosphere work environment.

Equipment selection is a process in which a series of information is needed, the most important being:

- Classification of the hazardous area and requirements regarding the level of protection, when applicable;
- Classification of gases, vapors or mists, in relation to group or subgroup of equipment;
- Temperature class;
- Application for which the equipment is intended;
- External influences and ambient temperature.

3.1. The relationship between equipment protection levels (EPL) and zones

When only areas are identified in area classification documentation, the relationship between EPL and areas, from Table 1, must be respected.

Table 1. Equipment Protection Levels (EPLs) when zones only are assigned
Area Equipment Protection Levels (EPLs)

Area	**Equipment protection levels (EPLs)**
0	„Ga”
1	„Ga” sau „Gb”
2	„Ga”, „Gb” sau „Gc”

Area	Equipment protection levels (EPLs)
20	„Da”
21	„Da” sau „Db”
22	„Da”, „Db” sau „Dc”

When EPLs are identified in area classification documentation, the following equipment selection requirements must be met.

3.2. The choice of equipment depending on equipment group equipment

The electrical equipment must be chosen in accordance with Table 2.

Table 2. Relationship between gas/vapor subdivision and equipment group

Gas/vapour or dust subdivision	Permitted equipment group
IIA	II, IIA, IIB sau IIC
IIB	II, IIB sau IIC
IIC	II sau IIC
IIIA	IIIA, IIIB sau IIIC
IIIB	IIIB sau IIIC
IIIC	IIIC

Where equipment is marked to indicate use in a particular gas or vapor atmosphere, it must not be used for other gases or vapors without a thorough prior assessment by a competent body, the results of which indicate that the equipment is suitable for such use.

3.3. The choice of equipment according to the ignition temperature of the gas, vapors or mists

Electrical equipment must be chosen so that the maximum surface temperature does not reach the ignition temperature of any gas, vapor or mist that may be present.

If the marking of electrical equipment does not contain the ambient temperature range, then equipment is designed to be used in the temperature range of -20 °C to 40 °C. If the marking of electrical equipment contains ambient temperature range, then equipment is designed to be used in this range.

If the ambient temperature is outside temperature range, or there is an influence of temperature from other factors, such as process temperature or exposure to solar radiation, then the effects on equipment must be considered and the measures taken must be documented.

Symbols for the temperature classes marked on electrical equipment have the meaning indicated in Table 3.

Table 3. Margins setting

Temperature class required by zone classification	**Flash point of gas or vapor in °C**	**Allowable equipment temperature class**
T1	> 450	T1-T6
T2	> 300	T2-T6
T3	> 200	T3-T6
T4	> 135	T4-T6
T5	> 100	T5-T6
T6	> 85	T6

3.4. Choice of radiant equipment

The output parameters of lasers or other continuous wave sources of electrical equipment with EPL "Ga", "Da", "Gb" or "Db" must not exceed the following values:

- 5 mW/mm^2 or 35 mW for continuous wave lasers and other continuous wave sources, and

- 0.1 mJ/mm^2 for pulsed lasers or pulsed light sources with an interval between pulses of at least 5 s.

The output parameters of lasers or other continuous wave sources of electrical equipment with EPL "Gc" or "Dc" must not exceed the following values:

- 10 mW/mm^2 or 35 mW for continuous wave lasers and other continuous wave sources, and

- 0.5 mJ/mm^2 for pulsed lasers or pulsed light sources.

For equipment located outside a hazardous area, or certified to an edition of CEI 60079-0, [7], or CEI 60079-28, [9], where this requirement is not mentioned, these values may be confirmed by the equipment manufacturer.

Radiation in field of the optical spectrum, especially in the case of focusing, can become a source of ignition.

Sunlight, for example, can initiate an ignition if objects focus the radiation (e.g. a concave mirror, lenses, etc.).

Radiation from high-intensity light sources, for example photo flash lamps or some LEDs, is, under certain conditions, absorbed by particles, so that these particles can become a source of ignition.

In the case of laser radiation (e.g. for signaling, telemetry, monitoring, rangefinders), the energy or power density, even for unfocused beams at long distances, can be so high that ignition is possible. Here too, the heating is mainly caused by effect of laser beams on dust layers or by absorption in particles to the atmosphere. In particular, intense focusing can cause temperatures well above 1000 °C at the focus point.

Consideration must also be given to possibility that equipment producing radiation (e.g. lamps, electric arcs, lasers, etc.) may itself become an ignition source.

Consideration must also be given to possibility that equipment producing radiation (e.g. lamps, electric arcs, lasers, etc.) may itself become an ignition source.

3.5. Choice of ultrasonic equipment

For equipment installed in the hazardous area or installed outside it, but radiating inside the hazardous area, the output parameters of ultrasound sources of electrical equipment with EPL "Ga", "Gb", "Gc", "Da", "Db" or "Dc" must not exceed the following values:

- 0.1 W/cm^2 and 10 MHz for continuous sources,
- average power density of 0.1 W/cm^2 and 2 mJ/cm^2 for pulse sources.

For equipment located outside a hazardous area, or certified to an edition of CEI 60079-0 where this requirement is not mentioned, these values can be confirmed by the equipment manufacturer.

When ultrasound is applied, large amounts of energy released by the acoustic transducers are absorbed by liquid or solid materials. Heating may occur in the affected material and, in extreme cases, may heat the material above the minimum ignition temperature.

4. CONCLUSIONS

Explosion prevention and explosion protection are of major importance for occupational health and safety in order to minimize losses (both human and material).

The process of selecting electrical equipment for use in areas with potentially explosive atmospheres, generated by mixtures of air and oil, flammable gases or vapors, requires in-depth knowledge in this field.

This paper aims to increase safety in the choice of equipment used in potentially explosive environments, helping users who have no knowledge in this field but are determining factors in their purchase or use.

This process takes time and to increase its quality and to facilitate the correct selection of electrical equipment intended for use in such atmospheres, an application has been developed to be a useful tool for personnel working in the industries that process, store or carries flammable substances.

The issues presented in the paper provide technical staff with an easy-to-use, intuitive, fast and reliable tool for selecting explosion-proof electrical equipment. The equipment is selected in accordance with the safety and explosion protection in force and brings with it an increase in the level of health and safety at work in industries with potentially explosive atmospheres.

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ASPECTS OF THE STANDARDIZATION PROCESS FOR EXPLOSIVE ATMOSPHERES

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Abstract: *This paper provides an overview of standardization activity in the field of explosive atmospheres, both nationally and internationally, as well as the evolution of this activity in various sectors related to explosive atmospheres. The first part of the paper gives a brief overview of explosion risk, explosion prevention and protection, classification of explosive atmospheres, and factors influencing explosion protection. In the second part of the paper, the national standardization context is presented, together with the reference institutions in the field of standardization for or related to explosive atmospheres. On this occasion, the international institutions administering standards that have an impact on the regulation of explosive atmospheres at the national level are also presented. The last part of the paper presents an analysis of the changes in the representative standards in the field of explosion protection in light of the significant changes made in the current edition compared to the previous edition.*

Keywords: *standard, explosive atmospheres, risk of explosion*

1 INTRODUCTION

With the discovery of new energy sources during the Second Industrial Revolution at the end of the 19th century, the development of industries such as electrical engineering, chemicals, and the automobile industry began. The increasing use of flammable substances in the production process led to the emergence of the concept of hazardous locations or atmospheres, both in terms of the risk of fire and the risk of explosions.

From that time to the present day, all those involved in these branches of industry (both the management of factories and plants and the authorities responsible for the sector) have contributed to the design, development, and issuing of protective measures and rules to be observed to avoid accidents at work in these hazardous atmospheres.

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Thus, in 1901, the first national standardization body in the world was set up in London under the name of the Engineering Standards Committee, which in 1918 became the British Engineering Standards Association [1].
In Romania, the first organization responsible for national standardization was set up in 1928 under the name of the Romanian Industry Standards Commission, from which the Romanian Standards Institute was later formed in 1970 [2].

2 EXPLOSION RISK

An explosion hazard arises when the flammable or combustible substance in the atmosphere is in sufficient concentration to form, together with the surrounding air, a mixture that may be ignited in the presence of an effective ignition source. The risk of explosion can be prevented by the application of specific measures either to prevent the formation of an explosive atmosphere or to prevent its ignition.

The formation of an explosive atmosphere can be prevented by limiting the concentration of the flammable substance, using an effective ventilation system and a concentration monitoring system. The ignition of explosive atmospheres can be prevented by separating the ignition source from the explosive atmosphere, by eliminating it, or by limiting its ignition capacity. The ignition source may be:

- of a thermal or electrical nature from electrical or mechanical equipment used in that atmosphere or
- caused by static electricity, lightning, electromagnetic waves, ionizing radiation, ultrasound, adiabatic compression, shock waves, and exothermic reactions.

In addition to measures to prevent the risk of explosion, protective measures are applied to limit the consequences of an explosion. This objective is implemented by stopping the explosion and/or limiting its extent to an acceptable level using protective systems.

Depending on the type of flammable or combustible substance present in the atmosphere (gas, vapor, or dust), the frequency and duration of occurrence, the degree and rate of release, and the type and degree of ventilation used to dilute the concentration of the flammable or combustible substance, explosive atmospheres have been classified into zones:

- flammable gases/vapors: Zone 0, Zone 1, Zone 2 [3];
- combustible dusts: Zone 20, Zone 21, Zone 22 [4].

This classification of explosive atmospheres into zones, together with the group classification of gases, vapors, or dusts and their ignition temperature, is an important criterion for the selection of electrical or non-electrical equipment to be used in these zones.

Depending on the type and functional role of the equipment, protective measures, and techniques, referred to as explosion protection types for electrical and non-electrical equipment, have been designed and developed so that they can be used safely in potentially explosive atmospheres [5].

The explosion protection of equipment and installations intended for use in potentially explosive atmospheres is influenced by three factors:

a) design, erection, and commissioning activities;

b) use/operation, inspection, and maintenance activities;

c) environmental factors such as humidity, temperature range, presence of corrosive substances, and presence of dust.

These factors are shown graphically in Figure 1.

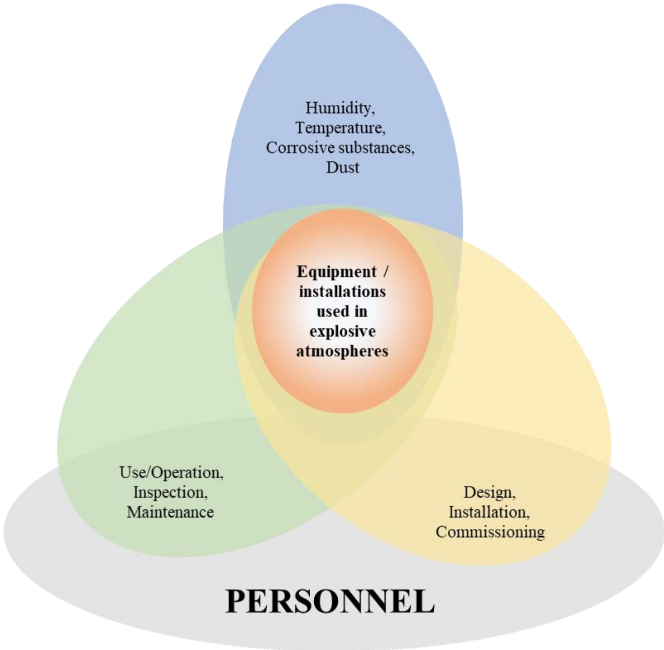

Figure 1. The factors which influence explosion protection

All these aspects of explosion protection have been and are included in the specific standards for explosive atmospheres, which have become the basis for the implementation of occupational safety and health requirements.

3 NATIONAL, EUROPEAN, AND INTERNATIONAL STANDARDIZATION CONTEXT

3.1 In Romania

Currently, in Romania, the Romanian Standardization Association (ASRO) is the national standardization body [6]. It was established in 1998 as a non-profit association by taking over the assets of the Romanian Standards Institute and the National Training and Management Center for Quality Assurance.

The standardization activity within ASRO is organized into 14 standardization sectors (fields of activity), comprising 399 technical committees (TC), of which 358 are currently active. The composition of each TC includes:

- Members,
- chairman,
- Secretary,

- ASRO expert.

The work carried out within the technical committee includes, among others, the development of new original Romanian standards and their maintenance, the adoption of standards and other European and international standardization documents as Romanian standards, and the development of the Romanian version of the European and international standards adopted at the national level. Also, an important aspect of the Technical Committee's activity is the participation in the European and international standardization activity through the designation of Romanian experts in the working groups of the European and international technical committees for which there is interest.

When developing an original Romanian standard, the following steps are followed:

- Submission to ASRO of the proposal for a new standard topic by the proposer, accompanied by the preliminary draft of the proposal to be assigned to the relevant technical committee;
- the preparation and approval of the draft in the Technical Profile Committee;
- forwarding the committee draft to the ASRO representative to start the public inquiry;
- implementing the comments received as a result of the public inquiry in the draft standard to be submitted for approval to the ASRO's specialized departments;
- submitting the draft standard to the Director General of ASRO for approval and publication.

The adoption of standards and other European and international standardization documents (e.g. technical reports or specifications, guides) as Romanian standards can be done by the following methods:

- Publication of the Romanian version;
- publication by reproduction of an official version (English, French, or German), i.e. via the confirmation tab;
- the method of confirmation of adoption by the publication of a notice (note of confirmation) in the "Standardization Bulletin".

At the national level, standards in the field of explosive atmospheres are included in the sector 'Electrical and electronic equipment' through the technical committee ASRO/CT 137 Equipment for explosive atmospheres.

3.2 In Europe

Today, at the European level, there are three European standardization organizations officially recognized by the European Union [7, 8]:

- The European Committee for Standardization (CEN), established in 1961; is responsible for standardization in all sectors of life and brings together the national standardization bodies of 34 European countries.
- The European Committee for Standardization in Electrotechnics (CENELEC), was set up in 1973; it develops standards in the field of electrotechnics and brings together the national standards bodies of 34 European countries.

- European Telecommunications Standards Institute (ETSI), set up in 1988 and responsible for standardization in the field of information and communication technology.

All these organizations have the role of developing standards in support of European Union regulations and policies and are the only ones recognized as European Standards (EN). ASRO is a full member of all three European standardization organizations.

At the European level (CEN and CENELEC), standards in the field of explosive atmospheres are included in the "Occupational Health and Safety" sector through the technical committees CEN/TC 305 (Potentially explosive atmospheres - Explosion prevention and protection) and CLC/TC 31 (Electrical apparatus for potentially explosive atmospheres). The standards developed in these technical committees fall under the scope of the ATEX Directive (2014/34/EU), which aims to create a single European market for products in explosion-protected construction [9].

To achieve this goal, several conditions must be satisfied simultaneously:

- Standards that meet the technical requirements of the ATEX Directive must specify unambiguous criteria for compliance.

- Notified Bodies for conformity assessment must be technically competent, and operate impartially and efficiently to impose minimum costs on industry and not delay work.

- There should be a mechanism to enable notified bodies to harmonize their practices to reduce differences between bodies in the application of the technical requirements of harmonized standards.

- The European Commission and the Member States, through the competent authority at the national level, should oversee the application of the ATEX Directive by implementing the most appropriate level of safety economically.

The National Institute for Research and Development in Mine Safety and Protection to Explosion INSEMEX Petroșani is the national body recognized by the European Commission (NOTIFIED BODY NB1809) for conformity assessment of products covered by the Directives [10]:

- Directive 2014/34/EU "Equipment and protective systems used in potentially explosive atmospheres - ATEX",
- Directive 2014/28/EU 'Explosives for civil uses',
- Regulation 2016/425 'Personal Protective Equipment',
- Directive 2013/29/EU "on the harmonization of the laws of the Member States relating to the making available on the market of pyrotechnic articles".

3.3 Internationally

At the international level, there are two recognized standardization organizations:

a) The International Electrotechnical Commission (IEC), founded in 1906 in London, aims to develop and publish international standards for all electrical, electronic, and related technologies. It brings together over 170 member countries and administers 4 conformity assessment systems [11]:

- IEC system of conformity assessment schemes for electrotechnical equipment and components (IECEE).

- IEC Scheme for Certification to Standards for Equipment for Renewable Energy Applications (IECRE).

- IEC Scheme for certification to standards for equipment for use in potentially explosive atmospheres (IECEx).

- IEC quality assessment system for electronic components (IECQ).

b) The International Organization for Standardization (ISO), founded in 1947 in Geneva, aims to develop and publish standards for all technical and non-technical fields other than electrical and electronic engineering. It brings together 168 national standardization bodies [12].

ASRO is a full member of both IEC and ISO.

At the international level (IEC), standards in the field of explosive atmospheres are managed by Technical Committee TC 31 (Equipment for explosive atmospheres) and Technical Subcommittees SC 31G (Intrinsically-safe apparatus), SC 31J (Classification of hazardous areas and installation requirements), SC 31M (Non-electrical equipment and protective systems for explosive atmospheres).

To facilitate international trade in equipment and services for use in explosive atmospheres, global unification of standards is necessary. Concrete actions to this end have been initiated through the initiation of permanent technical cooperation agreements between CEN and ISO and between CENELEC and IEC.

The Vienna Agreement between CEN and ISO was signed in 1991 and sets out two essential modes for the collaborative development of standards: the ISO-led development mode and the CEN-led development mode, whereby documents developed within one body are notified to the other for simultaneous approval by both bodies [13].

The Dresden Agreement between CENELEC and IEC was signed in 1996, and after 20 years of fruitful partnership, the cooperation between the two organizations was reconfirmed by the signing of the Frankfurt Agreement in 2016. This agreement set the following targets: providing new CENELEC work items to the IEC, parallel voting on draft international standards, publication requirements, and the conversion of European standards into international standards [14].

4 DYNAMICS OF THE DEVELOPMENT OF EXPLOSION PROTECTION STANDARDS

Based on the analysis carried out for the standards mentioned in Table 1, as regards the evolution of standardization in the field of explosion protection, the following conclusions can be drawn [15]:

- At the national level, the first standards for equipment used in potentially explosive atmospheres were the STAS 6877 series, published in 1973. Initially, they were intended exclusively for electrical equipment and only for gaseous explosive atmospheres. In 1995, the STAS 6877 series was replaced by the SR EN 50014 - SR EN 50020 series, and this series was subsequently replaced by the SR EN 60079 series in 2005.

- Standards for electrical apparatus for use in the presence of combustible dust have been adopted as Romanian standards since 1989.

- The standards for non-electrical equipment for potentially explosive atmospheres were adopted as Romanian standards in 2003.

- Since 2010, a new edition of the SR EN 60079 series of standards has been adopted, in which the requirements of the standards for electrical equipment for gaseous explosive atmospheres have been merged with those for dust explosive atmospheres.

- SR EN 60079-28 is a relatively new standard (first edition in 2007) that adds safety requirements for a new category of equipment intended for use in explosive atmospheres, namely optical equipment.

- The standards SR EN ISO/IEC 80079-34, SR EN ISO 80079-36, SR EN ISO 80079-37, and SR EN IEC 60079-0 are evidence of the achievement of the objective of global unification of standards.

Table 1. Explosion protection standards

No.	Romanian Standard reference and year of publication	Year of previous edition	Romanian Standard title
1.	SR EN 1127-1:2019	2011	Atmosfere explozive. Prevenirea şi protecţia la explozie. Partea 1: Concepte fundamentale şi metodologie
2.	SR EN 1127-2:2014	2003	Atmosfere explozive. Prevenirea și protecția la explozie. Partea 2: Concepte fundamentale şi metodologie pentru minerit
3.	SR EN 15188:2021	2013	Determinarea comportării la autoaprindere a acumulărilor de praf
4.	SR EN IEC 60079-0:2018	2008	Atmosfere explozive. Partea 0: Echipamente. Cerinţe generale
5.	SR EN 60079-1:2015	2007	Atmosfere explozive. Partea 1: Protecţia echipamentului prin carcase antideflagrante "d"
6.	SR EN 60079-2:2015	2007	Atmosfere explozive. Partea 2: Protecţia echipamentului prin carcasă presurizată "p"
7.	SR EN 60079-7:2016	2011	Atmosfere explozive. Partea 7: Protecţia echipamentului prin securitate mărită "e"
8.	SR EN 60079-11:2012	2011	Atmosfere explozive. Partea 11: Protecţia echipamentului prin securitate intrinsecă "i"
9.	SR EN IEC 60079-15:2019	2003	Atmosfere explosive. Partea 15: Protecția echipamentului prin tip de protecție "n"

No.	Romanian Standard reference and year of publication	Year of previous edition	Romanian Standard title
10.	SR EN 60079-18:2015	2010	Atmosfere explozive. Partea 18: Protecţia echipamentului prin încapsulare "m"
11.	SR EN IEC 60079-25:2022	2011	Atmosfere explozive. Partea 25: Sisteme electrice cu securitate intrinsecă
12.	SR EN 60079-28:2016	2007	Atmosfere explozive. Partea 28: Protecţia echipamentelor şi a sistemelor de transmisie care utilizează radiaţie optică
13.	SR EN 60079-31:2024	2014	Atmosfere explozive. Partea 31: Protecţia echipamentului împotriva aprinderii prafului prin carcasă "t"
14.	SR EN IEC 60079-10-1:2021	2016	Atmosfere explozive. Partea 10-1: Clasificarea zonelor. Atmosfere explozive gazoase
15.	SR EN 60079-10-2:2015	2010	Atmosfere explozive. Partea 10-2: Clasificarea ariilor. Atmosfere explozive cu praf
16.	SR EN 60079-14:2014	2009	Atmosfere explozive. Partea 14: Proiectarea, alegerea şi construcţia instalaţiilor electrice
17.	SR EN IEC 60079-17:2024	2014	Atmosfere explozive. Partea 17: Inspecţia şi întreţinerea instalaţiilor electrice
18.	SR EN IEC 60079-19:2020	2011	Atmosfere explozive. Partea 19: Repararea, revizia generală și recondiționarea echipamentelor
19.	SR EN ISO 80079-36:2016	SR EN 13463-1: 2009	Atmosfere explozive. Partea 36: Echipamente neelectrice pentru atmosfere explozive. Metodă şi cerinţe de bază
20.	SR EN ISO 80079-37:2016	SR EN 13463-5:2011; SR EN 13463-6:2005; SR EN 13463-8:2004	Atmosfere explozive. Partea 37: Echipamente neelectrice pentru atmosfere explozive. Tip de protecţie neelectrică prin securitate constructivă "c", prin controlul surselor de aprindere "b", prin imersie într-un lichid "k"
21.	SR EN ISO/IEC 80079-34:2020	2012	Atmosfere explozive. Partea 34: Aplicarea sistemelor calității pentru fabricarea produselor Ex

These conclusions emphasize the continuous evolution and adaptation of standards in the field of explosion protection, reflecting the constant concern to improve safety and compliance in the use of equipment in hazardous environments.

The diagram in Figure 2 shows that some standards have seen far more minor changes than others. For example, SR EN IEC 60079-0:2018 and SR EN 60079-1:2015 are among the standards that have seen significantly more minor changes in their current edition than in the previous edition. These minor changes include clarifications, reductions in technical requirements, minor technical changes, and editorial corrections, indicating a constant concern for improving the clarity and accuracy of the standards.

The diagram in Figure 2 gives a clear picture of the distribution of these minor changes between the different standards analyzed, underlining the importance of continuous revision and updating of explosion protection standards.

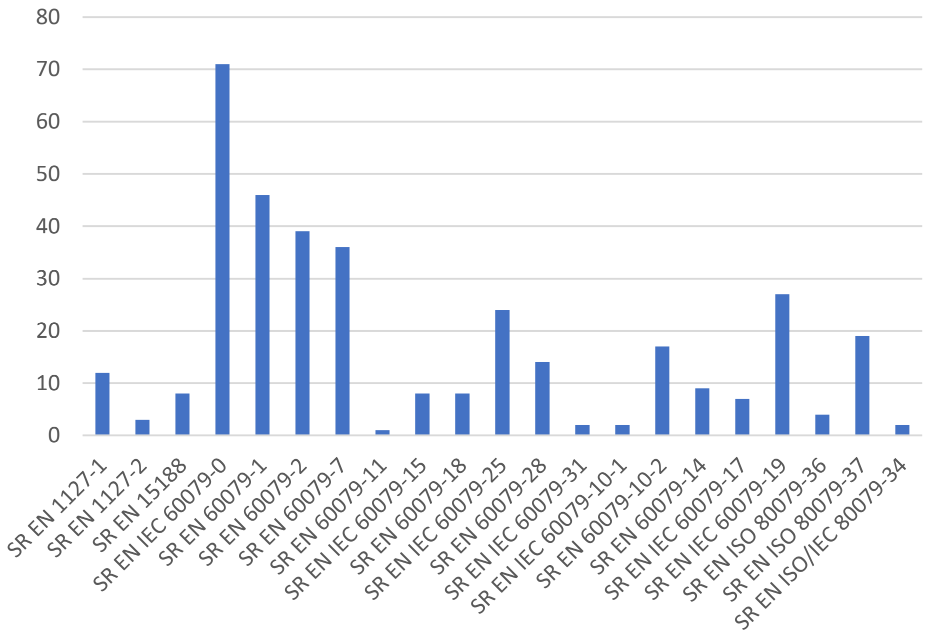

Figure 2. Highlighting the number of minor and editorial changes

The diagram in Figure 3 shows the number of extensions for the current editions of the family of standards covering the field of explosion protection. Notable standards with a significant number of extensions include SR EN 60079-1:2015, SR EN IEC 60079-15:2019, and SR EN 60079-14:2014.

Extensions in this context refer to the addition of new technical options or the extension of existing requirements to cover new aspects or new technologies in the field of explosion protection. These changes reflect the continuous evolution of technology and safety requirements in the use of equipment in potentially explosive environments.

The diagram gives an insight into how these standards are updated to include new requirements and technological options, keeping them relevant and effective in the face of industry changes and technological progress.

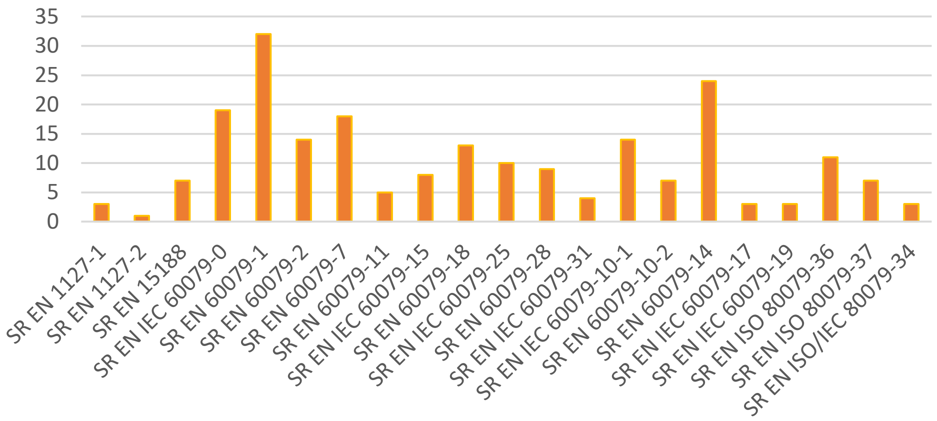

Figure 3. Highlighting the number of extensions

The diagram in Figure 4 shows the number of major technical changes to the standards in the family of standards covering the field of explosion protection. Notable standards that have seen major technical changes include SR EN IEC 60079-15:2019.

Major technical amendments indicate the addition of significant technical requirements or substantial changes to the standard that may affect the way equipment is assessed and certified for use in potentially explosive atmospheres. In the case of SR EN IEC 60079-15:2019, it is noted that a certain part of the standard's corpus has been transferred to other standards covering correlated types of protection from an explosion protection perspective. This change may reflect a reorganization of requirements or a clarification of the applicability of the standard in the context of technological or regulatory developments.

The diagram gives a clear picture of the evolution and adaptation of standards to meet new requirements and ensure adequate explosion protection in industrial environments.

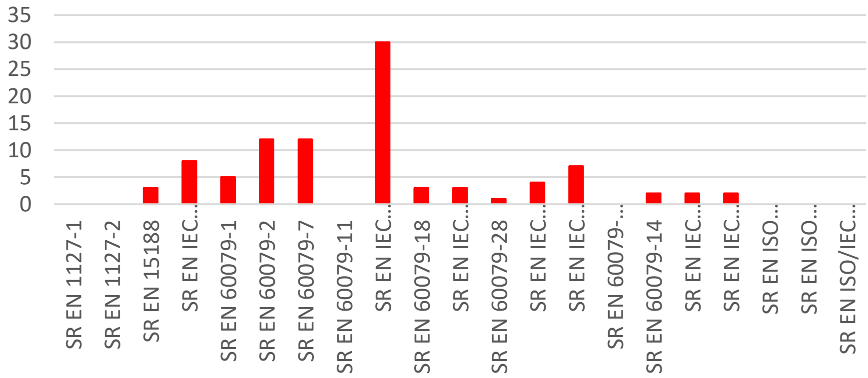

Figure 4. Highlighting the number of major technical changes

As a novelty, the forthcoming edition of the specific standard for the intrinsically safe type of protection covers, both on the requirements and on the testing side, several aspects such as isolation gaps and distances, non-failure conditions, possible failure scenarios, an extension of the range of use to pressures below 0.8 bar, specification of conditions and tests for compounds including the maximum temperature of continuous use. Additional electronic components such as supercapacitors and PTC devices were addressed.

5 CONCLUSIONS

Modernization of standards brings with it an increase in the complexity of technical solutions. This is necessary to ensure more precise regulation and to cover a wider range of concrete application situations. Standardization thus becomes more detailed and specific, addressing different implementation scenarios and technologies.

As far as minor and editorial changes are concerned, most changes have been implemented for the standard on general requirements for electrical equipment followed by the standards on flameproof enclosures, pressurized enclosures, enhanced safety, intrinsically safe electrical systems and the standard for classification of combustible dust zones.

New technical challenges and the need to keep the standards for types of explosion protection current and relevant with the pace of technical development have led to the updating of the standards for repair. Types of protection, such as explosion-proof enclosures, the installation standard, and the general requirements standard, have benefited from the most extensions. This underlines continuous efforts to respond to market requirements and to integrate innovations in the field.

Due to the need to keep in synchronization with the latest technical and explosion protection developments, the type of protection "n", flameproof enclosure type of protection and increased safety type of protection have benefited from the most major technical changes.

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EXPLOSION RISK PREVENTION IN A FOUNDRY HALL - CASE STUDY-

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Abstract: *The development of material batches in a foundry hall presents a series of five specific risks of which the most common, characterized as risk level 2 and 3 is represented by fires / explosions caused by solid materials, liquids, gases (combustible materials). The risk of explosion, a serious danger, is present in: batches of wet materials, working tools or additives. When the molten metal comes into contact with water, moisture or wet material, the water instantly transforms into vapor, expanding its volume 1600 times and at a temperature above 1000ºC it dissociates into component elements (hydrogen and oxygen) and produces a violent explosion, creating a dangerous situation for workers. Such an incident took place in a foundry hall in the exhaust system of a medium frequency induction heating furnace, during the development of a brass batch, bronze. In order to reduce the risk, a series of actions and corrective measures were applied, modification of work instructions, modifications and improvements of the gas exhaust installation, as a result of an event analysis and elaboration of a study, which is the subject of this paper.*

Key words: *furnace, temperature, explosion, brass, gas exhaust.*

1 INTRODUCTION

In the industrial hall of a company, equipped with a foundry platform, in the flue gas exhaust installation, a dangerous incident occurred during the night shift. There were no casualties, but the exhaust plant was damaged. The incident occurred during the development of the material batch after the brass briquettes were placed in the oven.

The fire occurred at the beginning of the night shift, resulting from the ignition of briquettes residues inserted in the pouring pot. The flame spread through the exhaust pipe, triggering the automated extinguishing equipment that protects the filtration area.

After the fire extinction, the activity resumed, but another fire started within the last hour of the shift, having more serious consequences caused by an explosion type incident in the exhaust pipe, resulting in ignition of the installation's filter elements.

The fire / explosion phenomena took place during the activity of the same operating personnel, while using brass chip briquettes from the same batch.

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In order to prevent dynamic events such as fires / explosions, a study was developed in which the following were analysed: technological processes carried out in the foundry platform, exhaustion of gases and vapours, samples of residues from exhaust pipes and filters, samples of briquettes, lubricants, emulsion and degreasers. Also, several hypotheses / scenarios for fires / explosions occurrence were elaborated. The study was completed with proposals to improve technological measures to prevent the analyses phenomena [1].

2 TECHNOLOGICAL PROCESS ANALYSIS

2.1. Technological flow within the foundry platform

The technological flow in the foundry platform hall consists of [2]:

• Melting installation (INDUCTOTHERM induction heating furnace) with a capacity of 2 x 1700 kg for brass, bronze, medium frequency (figure 1a) served by 2 casting pots (figure 1b);

• 760 kw Trak power and control unit, supplies 2 furnaces (ingots) and supplies power continuously and simultaneously to both furnaces during melting loads, ensuring maximum power conversion efficiency for the melting system, for a proper melting rate;

• Power unit monitoring system;
• 1025 KVA, 20 kV transformation system;
• Transformer connection cable set - Trak;
• Set of main line bars and water-cooled cables for oven supply;
• Hydraulic unit and pressure working system;
• External circuit water recirculation pumps;
• Cooling water dispensers for the furnace coil;
• Closed-circuit water-cooling radiator.

The foundry platform is equipped with transport and lifting installations, and the ventilation system is provided by the Handte exhaust installation, with a nominal flow of Qn=24000 Nm^3/h.

The amount of molten material from the 2 furnaces (ingot moulds) is processed in two centrifuges placed in the vicinity of the platform (figure 1c).

Figure 1. a) Electric furnace; b) Pouring pots; c) Centrifuge

2.2. Making the brass batch

The crucible induction electric furnace is generally used for making metals or alloys. The operations required for the manufacturing process take place in a crucible, usually made of acid refractory materials. For this purpose, the crucible is provided on the outside with a coil of copper pipe, in the form of a solenoid, through which the cooling water flows. The inductor or the primary circuit of the transformer is thus formed, and the secondary circuit is represented by the metal load (inductor).

The crucible and inductor are fitted on a metal housing connected to a tilting device in order to evacuate the alloy in liquid state.

Work at the brass batch processing furnaces is structured in 7 recipe variants, where the maximum load is 1700 kg, and the installation is operated by qualified, authorized and trained operating personnel in compliance with the company's own health and safety instructions at work for foundry [3].

The maximum quantities of Cu waste in the recipe variants are used only when necessary, to reduce the content of impurities, allowed only with the approval of the management staff and after consulting the technologist.

When making a batch, after emptying the oven, it can be loaded with materials according to the following working variants (schemes):

• Option I-III can be loaded with dry scrapings and brass waste;

• Variant IV-VI can be loaded with a maximum quantity of 500 kg briquettes and dry scrapings or brass waste, and given that there is still liquid material in the oven, it is cooled by adding a maximum quantity of 100 kg, proportional to the amount of liquid, after which briquettes are brought in;

• Variant VII - which can be performed only with the consent of the management, allows the melting of a quantity of 1400 kg briquettes.

2.3. Gas and vapor exhaust

Within the foundry hall there are 4 systems for evacuation, insertion and filtration of dust and harmful substances from the air, namely [4]:

• The HANDTE installation serves the induction furnace and the centrifugal casting machine;

• ALWO system that serves the induction furnace and the centrifugal casting machine;

• ALWO system that serves centrifuges and preheating pots;

• HOLTRUP treatment system that exhausts dust from the area of centrifuges and pots.

As the dangerous incident occurred in the HANDTE installation, the analysis will be developed only for this ventilation system (figure 2).

To reduce amounts of substances released into the atmosphere, a dry purification system, consisting of a cyclone (type Z) and a Jet Puls bag filter from HANDTE Germany is fitted on the evacuation route of dust resulted from the two induction processing furnaces and the two centrifugal casting machines.

The dedusting plant is intended for purification of air containing dust and harmful substances. This installation is type AAS-SL-22 /7-2.25 and has the following technical data:

- Volume flow 22,000 m^3/h
- Temperature 50°C
- Filter medium: Synthetic fibres
- Installed power: 7 kw

Components of the dust removal system are:

- Surface filter type: AAS-SL;
- The helical conveyor;
- Motor driven double pendulum flap;
- Radial blower (centrifugal fan) type: MXE 080-035515-00.

The cyclone is a component of dust removal installations, with the widest use in practice, having the main role of retaining large industrial dust with a very good yield and low cost, and for fine dust, it can be a very advantageous first step of separation. The separation effect of the cyclone is based on the centrifugal action.

Figure 2. HANDTE installation and cyclone

3. RISKS THAT OCCUR DURING THE BATCH DEVELOPMENT PROCESS

Specific risks are present when making material loads within the foundry platform, among which: explosion risk, fire risk, gas poisoning risk, mechanical injury risk and other residual risks. We will focus our analysis only on the risk of fire / explosion.

Analysis of the risk matrix elaborated annually by the personnel with responsibilities in Safety and Health at Work within the economic agent showed that the most frequent specific risk, characterized as risk level 2 and risk level 3, is represented by fires / explosions caused of solid materials, liquids, gases (combustible materials) [5].

The risk of explosion is present in batches of wet materials (a serious danger) or when working with wet or watery tools or additives. When the molten metal comes in contact with water, moisture or wet material, water instantly turns into vapor, expanding its volume 1600 times and, at a temperature above 1000°C, it dissociates into components, hydrogen and oxygen, that produce a violent explosion.

An explosion of water and molten metal can occur in any type of furnace. For the induction furnace the effects may be more serious because additional explosions may occur caused by contact between the perforated pipes of the cooling system and the molten metal. For an explosion to occur, it is not necessary for molten metal to be in the furnace.

Explosions may also occur if sealed containers are placed in an empty but hot oven. In this case, the force of the explosion may evacuate the inserted container and damage the refractory lining.

In the case under analysis, the fire / explosion phenomena took place during the activity of the same operating personnel using brass chip briquettes from the same batch. The sequence of events during 8 hours, was: the first incident, a small fire eliminated by the automatic extinguishing system at the beginning of the shift, and the second one, an explosion in the exhaust system (figure 3), at the end of the working program.

In accordance with the furnace operating instructions and the operating instructions for making the batch, the operator has carried out the following activities:

• Choosing the working variant, according to available raw material. They opted for the recipe from variant VI, adding 32 kg of Cu and 1.5 kg of A 421 flux, at 04:42, with a remaining quantity of 50 kg of liquid brass, after which proceeding to loading the oven with 782 kg of briquettes, at 4:48;

• The power potentiometer of the oven was operated to 460 kw, and after 22 minutes (5:14), the briquette residue caught fire and the pipeline exploded.

Figure 3. Component of the HANDTE exhaust system thermally damaged by the explosion

To reduce the risk, a series of corrective actions and measures were applied, modification of work instructions, modifications and improvements of the gas exhaust installation.

4. POST-EVENT MEASUREMENTS IN THE FOUNDRY HALL

4.1. Gas concentration measurements

Concentrations of flue gas resulted from making brass batches were measured, by using the portable multi-gas type X-am 7000 Drager analyser.

Gas measurements were performed at different stages of batch development.

When inserting the briquettes into the furnace and processing them, to obtain the molten material. Measurement time: about 5 minutes, after the moisture evaporation phase.

a) Gas concentrations measured at the entrance of the furnace, before reaching the exhaust system:
   O_2=17,5-18,5 % vol.
   CO_2=0,5-1,5 % vol.
   CH_4=4,4-4,6 % vol.
   H_2S=1-43 ppm
   CO=0,002-1,0 % vol.
b) Gas concentrations measured at the addition of LOGAS 50 pellets for degassing:
   O_2=20,3 % vol.
   CO_2=0,25 % vol.
   CO=0,002 % vol.
c) Gas concentrations measured when transferring the liquid material into the pouring pot:
   O_2=20,0 % vol.
   CO_2=0,25 % vol.
   CO=0,002 % vol.
d) Gas concentrations measured in the exhaust pipe:
   O_2=20,5 % vol.
   CO_2=0,20 % vol.
   CO=0,0015 % vol.

4.2 Measurements in ventilation installations

According to Standard NVIV-01-06, we performed measurements of the installation's functional parameters (suction pressure, effected air flow, power absorbed by drive motor, useful power), aerodynamic parameters of the ventilation ducts (section of the ventilation duct, length of the ventilation section, static pressure / depression, air flow) as well as air condition parameters (air speed, air temperature, relative humidity and absolute air pressure) at the four installations in the foundry section [6].

5. SAMPLING AND LABORATORY TEST

The following samples were taken at the event's site for research and laboratory tests: dust taken from the dust bag and the cyclone, brass briquettes, wet and dry brass foam, deposits in the exhaust pipe, fondant pellets (LOGAS), different types of oils (220, HLP 46, LPG 46), liquid residues from pellet squeezing and turning coolant. Using equipment endowment of the laboratory of physical-chemical analyses, laboratory tests were performed.

5.1. Determination of the flash point of liquids used in the manufacturing process

In order to determine the flash point of flammable liquids, the Pensky Martens with closed vessel automatic device for determining the flash point type, automatic type Petrotest PMA 4 (figure 4) was used [7].

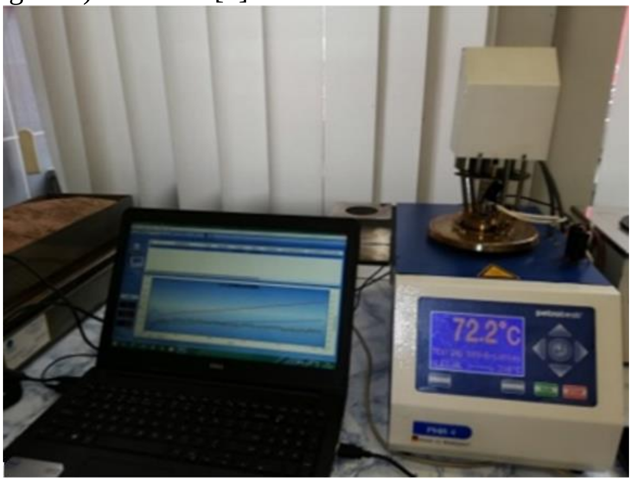

Figure 4. Pensky Martens device

Following the analyses conducted on the oil samples, it was found that the flash point ranges from 190.5 to 209.1°C, confirming that the samples are flammable.

5.2. Determination of the Autoignition Temperature of Flammable Gases and Liquids

To determine the autoignition temperature of flammable gases and liquids, the setup shown in figure 5 was used [8].

Figure 5. Setup for determining the autoignition temperature of flammable gases and liquids

Following the analyses conducted on the samples collected, it was found that the autoignition temperature ranges from 360º to 510°C, confirming that the samples are flammable.

5.3. Determination of the Minimum Ignition Temperature of Combustible Dust Clouds

The ignition temperature of a dust cloud: the lowest temperature of the hot inner wall of an oven that causes the ignition of a dust cloud in the air inside it. The equipment used for determining the minimum ignition temperature of the combustible dust cloud is shown in Figure 6.

Figure 6. Test stand for determining the ignition temperature of a dust cloud

Following the test, it was found that at the maximum oven temperature of 1000°C, according to the testing standard, ignition did not occur as specified in the standard requirements.

5.4. Determining the Minimum Ignition Temperature of a Dust Layer

The minimum ignition temperature of a dust layer: the lowest temperature of a hot surface at which ignition occurs for a specified thickness of dust layer deposited on this hot surface. The equipment used for determining the minimum ignition temperature of the combustible dust layer is shown in Figure 7.

Figure 7. Test stand for determining the ignition temperature of a dust layer

The test revealed that at the maximum temperature of 400ºC of the heated surface, according to the testing standard SR EN 50281-2-1, ignition did not occur as specified in the standard requirements [9].

5.5 Analysis of the samples collected through instrumental analysis

The samples collected from the site of the incident were analyzed using both thermal analysis (TG) with the coupling of a thermogravimetric analyzer Labsys Evo and FTIR equipment of Nicolet IS 50 type, as well as infrared spectrometry (FTIR) using Nicolet IS 50 equipment with an integrated ATR module with diamond crystal, in the range of 4000 – 400 cm^{-1}[10].

Thermal analysis comprises a set of investigation methods where the physical or chemical properties of a substance, a mixture of substances, and/or reaction products or mixtures thereof are measured as a function of temperature or time. To perform these determinations technically, the temperature of the analyzed product is modified according to a well-established and controlled program. Throughout the temperature modification, the monitored physical property is continuously measured, resulting in an automatically generated graph (thermogram) that plots the change in physical property on the ordinate and the temperature change on the abscissa.

The coupling of thermogravimetric analysis (TG) with FTIR allows for the analysis of gases resulting from thermal decomposition, oxidation, etc., occurring during the programmed heating of the samples [11,12,13].

In this case, we analyzed a sample of 220 grade oil using the coupled thermal method and FTIR spectrometry. The initial mass of the sample was 68.5 mg. The sample was subjected to a heating process at a temperature of 1000°C with a heating rate of 10°C/min, and the program duration was 172 minutes.

From the thermogravimetric analysis, it was observed that within the temperature range of 209.50 to 453.25°C, there was a mass loss of 66.94 mg. The thermogram obtained is shown in Figure 8, and the spectrum of the sample is depicted in Figure 9.

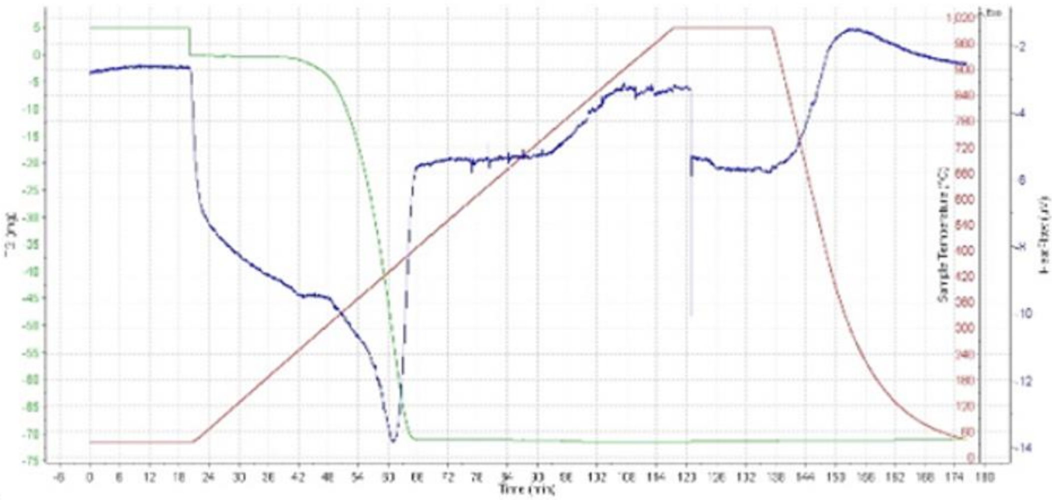

Figure 8. Thermogravimetric analysis (TGA) curve of the sample of Oil 220

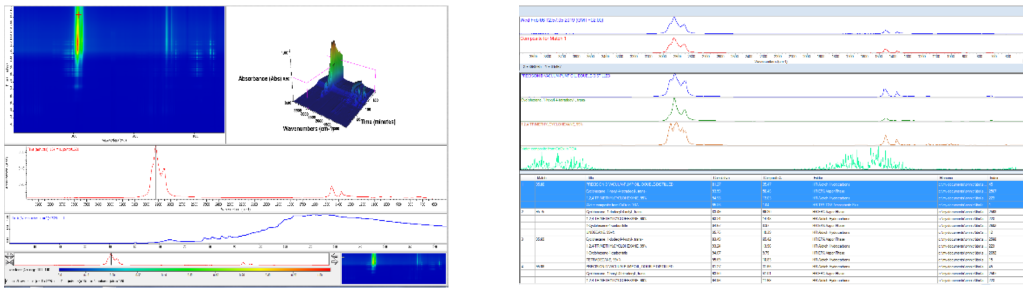

Figure 9. The spectrum of the sample at minute 164

During the analysis of the Oil 220 sample using TG-FTIR coupling, hydrocarbons such as methane, ethene, cyclohexane, benzene, pentane, etc., were identified. These substances are commonly found in the composition of oils used in technological processes .

6. PRODUCTION SCENARIO OF THE EXPLOSION AND CONTRIBUTING FACTORS

6.1. Mechanism of explosion occurrence

Following direct measurements of gas concentrations released during the process of preparing brass charges, as well as instrumental analysis of oil samples taken from machining or briquette-making processes, and based on initial data contained in the event investigation form, the following scenario (mechanism) of the event can be outlined [1,14]:

• Moment 1: There is a remaining quantity of 50 kg of liquid brass in the furnace, and the operator opted for recipe variant VI, adding 32 kg of Cu and 1.5 kg of flux A421.

• Moment 2: The furnace was loaded with 782 kg of briquettes, and the power potentiometer of the furnace was set to 460 kW.

• Moment 3: Evaporation of moisture (visually observed as "white smoke" from the furnace).

• Moment 4: Release of combustion gases (visually observed as "dark-colored smoke") - carbon dioxide, carbon monoxide, hydrogen sulfide, methane (concentration at the lower explosive limit of 4.4-4.6% vol.), and other hydrocarbons (ethylene, hexane, cyclohexane, benzene, pentane, methylbutane) which reacted with oxygen to form an explosive mixture. These gases were present in the exhaust gas ducts and in the HANDTE cooling system.

• Moment 5: Initiation of gas explosion in the furnace and propagation of the flame front of the explosion through the existing gas medium in the installation, via the exhaust ducts and the cooling system, up to the filters.

• Moment 6: Triggering of fire in the exhaust system with its consequences, damaging the HANDTE installation.

• Moment 7: Extinguishing the fire.

Duration of the event (moments 2-6): 22 minutes, according to the event analysis sheet.

6.2. Favorable Factors

The event was facilitated by the following favorable factors:

• Moisture content in the brass shavings briquettes (briquettes from the same batch caused two incidents within 8 hours, one fire and one explosion/fire).

• Proximity of the HANDTE exhaust system cooling installation to the furnace where the charge was processed.

• Possible malfunction of the activation sensors of the STS extinguishing equipment protecting the filtration area, or too short response times compared to the propagation of the flame front in the exhaust ducts.

• High temperature in the furnace (700-1000°C) affecting the lower explosive limit of combustion gases, decreasing it, as well as the mixture of explosive gases or water dissociation into hydrogen and oxygen (water gases).

7. PROPOSALS FOR IMPROVING TECHNOLOGICAL MEASURES

To avoid dangerous situations such as explosions or fires, the following measures (or combinations thereof) can be implemented:

- Washing the brass shavings with a solvent or degreaser to remove residual oils from metal surfaces, preventing thermal cracking of oil residues during the melting process in the furnaces before briquetting, while taking all precautions to prevent the formation of potentially explosive and/or toxic mixtures.
- Using a reduced quantity of briquettes contaminated with oil in the preparation of charges.
- Regular inspection of ventilation systems.

- Operators performing daily and weekly maintenance of ventilation/exhaust systems and equipment to reduce accidental oil leaks.
- Doubling or increasing the air extraction flow to remove flammable vapor concentrations from explosive range. This would aim to achieve a maximum concentration of 5% vol. flammable vapors by doubling the aspirated flow above induction furnaces from a minimum measured flow of 10,620 m^3/h to 21,240 m^3/h.
- Using inert gases during the period when flammable vapors are released. For an estimated flow rate of flammable vapors of approximately 0.0295 m^3/s, achieving the Lower Oxygen Concentration (LOC) (approximately 12% O_2) requires an inert gas flow rate (CO_2 or N_2) of about 1.24 m^3/s. The atmosphere above induction furnaces (and in exhaust ducts) could be represented proportionally as follows: 1% flammable gases, 42% inert gas, 12% O_2, 45% N_2.
- Keeping the valves of the ventilation/exhaust system open.
- Collecting emulsions from the brass shavings collection vessels to reduce oily residues.
- Conducting analyses to reduce the quantity of oils used without affecting the necessary technological processes for normal operations.
- Periodic assessment of explosion risks in installations where potentially explosive materials/substances are used.

8. CONCLUSIONS

A dangerous incident resulting in material damage occurred during a night shift in an industrial hall of a commercial company equipped with a foundry platform. The incident occurred in the exhaust system of the combustion gases, initially as a fire and later escalated into an explosion during the processing of material charges, shortly after introducing brass briquettes into the furnace, involving the same operator team using brass shavings briquettes from the same batch.

To ascertain the causes of the fire/explosion incident, analyses were conducted on the technological process, including the workflow from the foundry platform, the preparation of brass charges, the exhaust of gases and vapours from molten material, and the dust extraction system.

The process of preparing material charges in the foundry platform involves specific risks, including explosion risk, fire risk, gas intoxication risk, mechanical injury risk, and other residual risks. From the risk matrix analysis conducted, it was determined that the most frequent specific risk, categorized at risk levels 2 and 3, is related to fires/explosions caused by solid, liquid, and gas combustible materials.

Measurements of gas concentrations, post-event, conducted in the foundry hall using a portable gas analyzer during various phases of batch processing detected methane concentrations emitted at the lower explosive limit (LEL) of CH4=4.4% by volume at the furnace mouth, prior to entry into the exhaust system. This explains the formation of an explosive methane-air mixture in the ventilation system and the occurrence of the explosion/fire phenomenon.

Laboratory tests performed on samples collected from different types of oils (220, HLP 46, GPL 46), liquid residues from pellet pressing, and cooling lubricant from turning have demonstrated that these materials are flammable at temperatures ranging from 190.5-510°C. Analysis of the Oil 220 sample using TG-FTIR coupling identified hydrocarbons such as methane, ethene, cyclohexane, benzene, pentane, etc., substances typically found in the composition of oils used in technological processes.

Based on the scenario of fire/explosion phenomena production, the mechanism of event occurrence, and contributing factors, a series of improvements to technological measures have been proposed to prevent the formation of potentially explosive and/or toxic mixtures.

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CONSIDERATIONS IN CHOOSING EQUIPMENT FOR EXPLOSIVE ATMOSPHERES

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Abstract: *In potentially explosive environments, equipment used for generating, distributing, storing, measuring, regulating, transmitting, and consuming electrical energy requires additional constructive measures to prevent any ignition source that could trigger an explosion. This ensures operational safety in the presence of explosive atmospheres through the unique characteristics of each type of protection. The selection of electrical equipment for use in potentially explosive environments requires an understanding of the classification of hazardous zones for gases, vapors, and dust, as well as knowledge of temperature classes. To ensure workplace safety and minimize the risk of explosions in potentially explosive environments, it is essential to take all necessary measures regarding the maintenance, inspection, and correct use of electrical equipment and connection devices. A key conclusion is that once the correct zoning of potentially explosive areas has been achieved, it is possible to proceed with the design of the electrical installation using certified electrical equipment for those zones. This approach ensures that the use of equipment strictly complies with existing regulations and is compatible with specific zoning.*

Key words: *Explosive atmosphere, electrical equipment, temperature classes, maintenance.*

1 INTRODUCTION

The choice of equipment for an installation with an explosive atmosphere requires a detailed and rigorous process to ensure safety and compliance. The main stages include:

A. Risk Assessment and Identification

Identifying hazardous substances (gases, vapors, dust) and determining their characteristics (flash point, auto-ignition temperature).

Classifying zones based on the probability and duration of the presence of explosive atmospheres: Zones 0, 1, 2 for gases and vapors, and Zones 20, 21, 22 for dust.

B. Gas Group and Dust Group

Equipment must be compatible with specific gas groups (IIA, IIB, IIC) and dust groups (IIIA, IIIB, IIIC).

C. Zoning

Developing maps to clearly visualize and delineate explosion-risk areas.

D. Choosing the Type of Protection/Protection Methods

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Intrinsic safety (Ex i): Limiting electrical and thermal energy in explosive gas or dust environments.

Pressurization (Ex p): Operating equipment at high power in appropriate zones.

Encapsulation (Ex m): Protection for sensitive electronic devices and measuring equipment.

E. Verifying Temperature Requirements

Ensuring equipment compatibility with the specified temperature range and that the maximum surface temperature of the equipment does not exceed the auto-ignition temperature of the explosive atmosphere.

Equipment must fall within the appropriate temperature class (T1-T6).

Equipment must operate within the ambient temperature range of the hazardous area.

F. IP Degree of Protection

Selecting equipment with the appropriate IP degree of protection to ensure protection against dust and water ingress.

G. Certification and Compliance with Standards

Equipment must be certified according to ATEX, IECEx for use in explosive atmospheres.

Ensuring compliance with relevant standards IEC/EN 60079.

H. Installation/Training/Monitoring and Maintenance of Equipment

Installing equipment according to manufacturer instructions and safety regulations.

Adequate training of personnel on the use, maintenance, and inspection of equipment.

Implementing a preventive maintenance program and continuous monitoring to detect signs of wear or non-compliance. Conducting periodic inspections and updating risk assessments based on operational or regulatory changes.

These considerations are essential to ensure the correct and safe selection of equipment intended for hazardous areas, complying with safety standards and regulations in force [1].

2 HAZARDOUS AREA CLASSIFICATION

Zone 0 – Continuous presence of explosive gases.
Zone 1 – Likelihood of explosive gases present under normal operating conditions.
Zone 2 – Presence of explosive gases under abnormal conditions.
Zone 20 – Continuous presence of explosive dust.
Zone 21 – Likelihood of explosive dust present under normal operating conditions.
Zone 22 – Presence of explosive dust under abnormal conditions.
Based on the classification of zones in an industrial location with explosive potential, the equipment used must be selected and installed according to specific safety and explosion protection requirements. Here's how equipment is classified based on zoning:

Zone 0:

Equipment intended for Zone 0 must be designed and certified to operate in conditions where an explosive atmosphere is continuously present, frequently, or for long periods.

Examples: portable lamps, sensors, transmitters, measurement and control instruments. These must be constructed to avoid any source of sparks or heating that could trigger an explosion.

Zone 1:

Equipment used in Zone 1 must be designed to withstand the probable presence of an explosive atmosphere during normal operations.

Examples: lighting equipment, ventilation and aeration equipment, electric motors, control panels. These must be certified for operational safety in potentially hazardous environments.

Zone 2:

Equipment intended for Zone 2 must be capable of operating in conditions where the probability of an explosive atmosphere is low and, if it occurs, it is only for short periods.

Examples: industrial computers, switching equipment, power supplies. These must be designed to minimize ignition risks and ensure safe operation in potentially explosive environments.

2.1 Equipment Protection Types

Appropriate selection of electrical equipment is crucial for ensuring safety in potentially explosive environments, such as areas with flammable gases, vapors, or dust. International and European standards, such as IEC and ATEX, define the types of protection required in these specific conditions.

Intrinsic Safety

This type of protection is essential in potentially explosive environments, such as those with flammable gases, vapors, or dust. Equipment designed in this way is configured to operate with electrical circuits of limited power and energy, thus preventing sparks or sufficient energy generation that could trigger an explosion in the surrounding atmosphere. This form of protection is preferred in applications where other protection methods are not feasible, such as process control and monitoring in industrial environments with explosion potential. Individual components are carefully selected and mounted to minimize ignition risk, including the use of current limiters, protection diodes, and other energy and temperature management techniques [2].

Examples of equipment that use intrinsic safety include process sensors and transmitters for measuring and monitoring critical parameters in industry, controllers, and automation systems adapted for hazardous environments, measurement instruments such as gas analyzers, and control devices such as switches and command buttons. Also included are lighting and communication equipment specially designed to minimize ignition risk in explosion-risk areas.

Pressurized Enclosure

This protection method involves encapsulating equipment in a robust, pressurized enclosure with an inert gas. This high internal pressure prevents the ingress of flammable gases and minimizes ignition risk. Controlled ventilation maintains the internal gas pressure constant and prevents leaks, ensuring a safe environment inside the enclosure. Internal components are designed to keep temperatures low and avoid producing sparks in the explosive atmosphere. This protection method is used in industrial environments such as oil refineries and chemical plants, where flammable gases are present. The advantages include reducing ignition and explosion risk by maintaining a pressurized and safe environment inside the enclosure. Equipment with Ex p protection is designed to withstand harsh conditions in critical industrial environments [3].

Examples of equipment protected by pressurized enclosures include control cabinets and command panels. These are essential in modern industrial systems for controlling and monitoring processes and equipment. Control cabinets house electrical and electronic components such as PLCs, relays, sensors, and interface modules, providing protection against external factors such as dust, moisture, vibrations, and contaminants. They also ensure security against unauthorized access, often being equipped with locking and ventilation or cooling systems to maintain optimal operating conditions.

Command panels are physical interfaces through which operators control and monitor equipment, equipped with buttons, displays, and other devices for managing industrial processes. These can be integrated with PLCs and SCADA systems for automated control and real-time data collection.

By properly using these control cabinets and command panels, efficient and safe operation of industrial systems is ensured, contributing to process optimization and overall performance improvement of industrial operations.

Encapsulation

This method of protection involves the complete isolation of critical components in a solid material, thus preventing sparks or overheating that could trigger an explosion in the presence of flammable gases, vapors, or dust.

Key components of the equipment, such as electronic circuits, switches, and transformers, are placed in a fully enclosed or encapsulated housing. This approach ensures that no sparks or excessive heat that could ignite the explosive environment will occur. The material used for encapsulation can vary from plastic and ceramics to special fire-resistant resins, selected according to the specific application and environment requirements where the equipment will operate.

Equipment protected by Ex m is designed to have limited power and voltage, thus reducing the risk of sparks and overheating. These restrictions are defined in relevant certifications and standards. This form of protection is commonly used in the chemical industry, mining, refineries, and other industrial environments with the presence of flammable gases or vapors. It is also useful in environments with flammable dust, such as food processing and pharmaceutical factories [4].

The advantages of Ex m protection include significantly reducing the risk of ignition and explosion in potentially explosive environments and the ability of encapsulated equipment to operate reliably in harsh environmental conditions over the long term. However, the limitations imposed by encapsulation may restrict their use in complex industrial applications.

Ex m encapsulation protection is a robust and safe option for using equipment in hazardous environments, significantly contributing to reducing risks associated with explosions in explosive atmospheres.

3 TEMPERATURE CLASSES

In the context of equipment intended for use in potentially explosive areas, the term "temperature class" refers to the maximum surface temperature of the equipment under normal operating conditions. This temperature is not high enough to ignite the explosive atmosphere surrounding the equipment. Assessing the temperature class is essential to determine the risk of ignition and to select appropriate equipment for different hazardous areas.

Temperature classes are identified by letters and numbers from T1 to T6, with T1 indicating the highest allowable temperature and T6 the lowest. In this classification, T1 represents a maximum surface temperature of 450°C, and T6 a maximum surface temperature of 85°C. This classification is used to match the equipment with the auto-ignition temperature of the substances in the explosive atmosphere.

300°C < T1≤ 450°C
200°C < T2 ≤ 300°C
135°C < T3 ≤ 200°C
100°C < T4 ≤ 135°C
85°C < T5 ≤ 100°C
T6 ≤ 85°C

For example, if an environment contains a substance with an auto-ignition temperature of 180°C, the equipment must have a maximum surface temperature below this threshold to avoid any ignition risk. Thus, in this case, equipment in the T3 class (with a maximum surface temperature of 200°C) cannot be used safely in that environment. Instead, equipment in the T4 class (with a maximum surface temperature of 135°C) or lower must be chosen.

Choosing equipment according to temperature classes helps to ensure safe and reliable operation in environments with an explosion risk, significantly reducing the risk of ignition and explosion. This classification is essential for selecting the appropriate equipment for various potentially explosive areas and avoiding hazardous situations due to excessive heating [2].

Equipment is selected based on the auto-ignition temperature of the gases or dusts present in the environment. For instance, in an environment with methane gas (auto-ignition temperature of 537°C), equipment up to T1 is appropriate. Conversely, for a propane gas environment (auto-ignition temperature of 470°C), equipment must be T2 or better.

3.1 The Importance of Ambient Temperature

The ambient temperature refers to the temperature in the environment where the electrical and electronic equipment is installed and operated. It is an important consideration in the design and selection of equipment intended for use in hazardous locations with explosive atmospheres.

The ambient temperature influences the operating conditions and performance of equipment, including its ability to operate safely and efficiently in potentially hazardous environments.

In industrial applications, such as oil refineries, chemical plants, and manufacturing facilities, the ambient temperature can vary significantly due to factors such as weather conditions, process heat, and proximity to heat sources. These variations can affect the performance and reliability of electrical and electronic equipment, as well as the safety and operation of industrial processes.

It is essential to consider the ambient temperature when selecting equipment for hazardous locations to ensure that it is suitable for the specific environmental conditions and operating requirements. The equipment must be capable of operating within the ambient temperature range specified for the hazardous location and comply with the relevant safety standards and regulations.

The temperature range of the hazardous location is defined based on the maximum and minimum temperatures that may occur during normal operation. It is important to select equipment with an appropriate temperature rating and ensure that it can withstand the expected temperature variations without compromising safety or performance.

Proper installation and maintenance of equipment are also critical to ensuring safe and reliable operation in hazardous locations. Equipment should be installed according to manufacturer's instructions and safety guidelines, and regular maintenance should be performed to detect and address any issues that may affect performance or safety.

By considering the ambient temperature and selecting equipment with the appropriate temperature rating, industrial facilities can enhance safety, minimize risks, and ensure compliance with regulatory requirements for hazardous locations.

3.2 The IP Rating

In industrial and other applications, IP (Ingress Protection) refers to the international standard that defines the degree of protection of electronic and electrical equipment against the intrusion of foreign bodies (such as dust) and water penetration. IP is represented by the letters "IP" followed by two digits (or "X" in the case of unknown digits), with each digit providing specific information about the equipment's protection level.

Examples of IP ratings include:

IP65: Equipment is completely protected against dust (5) and protected against water jets (6).

IP54: Equipment is protected against limited dust ingress (5) and protected against water splashes (4).

IP68: Equipment is dust-tight (6) and can be submerged under water under specified conditions (8).

These IP ratings are crucial in determining the suitability of equipment for different environmental conditions, ensuring they meet necessary durability and safety standards.

The Ingress Protection (IP) rating defines the degree of protection provided by electrical and electronic equipment against solid objects (dust, dirt) and water. It is an important consideration when selecting equipment for use in hazardous locations with explosive atmospheres.

The IP rating consists of two digits:

The first digit indicates the level of protection against solid objects (e.g., dust).

The second digit indicates the level of protection against water (e.g., water jets, immersion).

The IP rating is assigned based on standardized tests and criteria specified in international standards, such as IEC 60529. Higher IP ratings indicate greater protection against solid objects and water.

When selecting equipment for hazardous locations, it is essential to consider the IP rating to ensure that it provides adequate protection against ingress of dust and water. Equipment with a suitable IP rating can withstand the environmental conditions and operating requirements of the hazardous location, ensuring safe and reliable operation.

For example, equipment used in outdoor environments or exposed to dust and dirt must have a sufficient IP rating to prevent ingress and ensure continuous operation. Similarly, equipment installed in wet or damp environments must be protected against water ingress to prevent damage and ensure electrical safety.

The IP rating should be specified by the manufacturer and verified through testing and certification according to international standards. It is important to select equipment with an appropriate IP rating for the specific hazardous location and application to minimize risks and ensure compliance with safety requirements.

By considering the IP rating when selecting equipment for hazardous locations, industrial facilities can enhance safety, minimize downtime, and protect against damage due to environmental factors.

4 FACTORS IN SELECTING EQUIPMENT

Equipment must be certified according to international standards such as IECEx or ATEX to ensure safety and protection against explosions. The selection of equipment should consider the appropriate temperature class to reduce the risk of ignition in the presence of flammable substances. Equipment should be chosen based on its degree of protection against dust and water (IP) to withstand specific environmental conditions in industrial locations.

Regular maintenance and periodic checks are essential to ensure the long-term proper and safe operation of equipment.

Correct equipment selection based on zoning is crucial to ensure a safe working environment and compliance with safety regulations in industries at risk of explosion. Maintaining equipment in these hazardous environments is critical for safety, reliability, and regulatory compliance, minimizing the risks of ignition and explosion.

Here are the main aspects and requirements for maintaining equipment in potentially explosive environments:

4.1 Maintenance Planning and Scheduling

Developing and implementing detailed preventive maintenance plans are crucial. These plans should include regular inspections, functional checks, and maintenance activities to prevent breakdowns and keep equipment in optimal operating conditions.

Equipment in explosive risk zones should undergo periodic checks and tests according to manufacturer recommendations and relevant standards. These checks may include insulation tests, IP protection verification, and other specific safety tests.

Operating and Maintenance Instructions

Operators and maintenance personnel must be well-trained in the correct use of equipment and maintenance procedures, following manufacturer specifications and standardized procedures.

All maintenance activities, inspections, and corrective interventions must be documented to ensure transparency and compliance with safety requirements.

Periodic risk assessments associated with operating equipment in potentially explosive atmospheres are necessary. These include identifying ignition sources, checking equipment integrity, and protection systems.

Any defects or issues discovered during inspections should be promptly rectified to minimize the risks of explosion or accidents.

Equipment and maintenance procedures must adhere to relevant international standards such as IECEx and ATEX, which regulate the use of equipment in hazardous areas.

Periodic inspections should be conducted to verify equipment and maintenance procedures compliance with applicable regulations and standards.

Maintaining equipment in potentially explosive environments requires a proactive approach to respond to changing environmental conditions and integrate new technologies that can enhance safety and reliability.

Reporting incidents and learning from them are crucial for improving maintenance practices and preventing their recurrence.

Maintenance of Ex equipment (designed for explosive atmospheres) is essential to ensure safety and proper functioning, reducing the risk of failures that could cause explosions and contributing to compliance with international and national regulations and standards.

Considerations for choosing equipment for explosive atmospheres are crucial in industrial risk management. This work significantly contributes by addressing important criteria for equipment selection in an explosive risk zone.

5 CERTIFICATION AND COMPLIANCE WITH STANDARDS

Certification and compliance with international standards are essential for ensuring the safe and reliable operation of electrical and electronic equipment in hazardous locations with explosive atmospheres. Equipment used in these environments must meet stringent requirements to minimize the risk of ignition and explosion.

International standards, such as ATEX (European Union) and IECEx (International Electrotechnical Commission), define the requirements for equipment design, construction, testing, and certification for use in hazardous locations. These standards specify the types of protection (e.g., intrinsic safety, pressurization, encapsulation) and performance criteria that equipment must meet to ensure safety and reliability.

When selecting equipment for hazardous locations, it is important to choose products that are certified and compliant with relevant international standards. Certification ensures that the equipment has been tested and approved by authorized third-party laboratories to verify compliance with safety requirements and performance criteria.

ATEX and IECEx certifications are recognized globally and provide assurance that equipment meets the highest standards of safety and reliability for use in hazardous locations. Equipment with ATEX or IECEx certification bears the appropriate markings and labels to indicate compliance with these standards.

In addition to certification, it is important to consider the specific requirements and conditions of the hazardous location when selecting equipment. Factors such as ambient temperature, presence of explosive gases or dust, and operational requirements should be carefully evaluated to ensure that the equipment is suitable for the intended application.

Proper installation, maintenance, and monitoring of equipment are also critical to ensuring safe and reliable operation in hazardous locations. Equipment should be installed according to manufacturer's instructions and safety guidelines, and regular maintenance should be performed to detect and address any issues that may affect performance or safety.

By selecting certified and compliant equipment and following best practices for installation and maintenance, industrial facilities can enhance safety, minimize risks, and ensure compliance with regulatory requirements for hazardous locations.

6 CONCLUSION

Environmental temperature is crucial for the safety and performance of equipment in potentially explosive atmospheres. Choosing equipment compatible with the specified temperature range and operating conditions is essential for safe and efficient operation. Consulting industrial safety experts and adhering to standards are recommended for long-term compliance and safety in industrial operations.

The IP (Ingress Protection) standard is essential for assessing equipment protection against foreign objects and water ingress, providing users with clear information on the appropriate use of equipment in various working environments.

Selecting explosion-proof electrical equipment is a critical decision in risk management within hazardous environments. It is essential to consult relevant standards and conduct a detailed risk assessment to choose the appropriate protection type for each specific application.

In conclusion, zoning is vital for safety in industrial environments with explosive risk, relying on accurate risk assessment and classification. This allows for the implementation of appropriate prevention and protection measures to ensure a safe working environment in accordance with standards.

Overall, the paper provides a comprehensive framework for selecting equipment intended for use in facilities where explosive atmospheres are present, emphasizing the importance of rigorous risk assessment, correct zoning, compliance with standards, and expert consultation to ensure a safe and compliant working environment.

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CFD SIMULATION OF CARBON DIOXIDE CIRCULATION DYNAMICS IN A VENTILATION INSTALLATIONS TUBING

Florin RĂDOI [1], Nicolae IANC [2]

Abstract: *Reducing the risk of occurrence of phenomena such as poisoning, as a result of the untimely penetration of a certain amount of asphyxiating gases, inside a ventilation installation, is a priority, regarding the health and safety of workers, material assets and the negative influence on the environment, due to the possible problems caused by the occurrence of asphyxiating atmospheres, formed by mixing air with these gases. In closed or semi-closed industrial and non-industrial buildings, effective ventilation is the primary measure to prevent toxic atmospheres. Knowing the behavior of asphyxiating gases as well as their manner of dispersion is essential for preventing hazardous circumstances at the level of inadequately aired ventilation facilities, where they could develop. For the study of the dynamics of carbon dioxide circulation inside the piping of an industrial ventilation installation under the influence of the air state parameters, the CFD technique was used with the help of the ANSYS MULTIPHISICS software package In order to carry out the simulation in a manner as close as possible to the experimental conditions, the topographic elevation of the ventilation installation was carried out within the experimental laboratory where the experiments were carried out in the laboratory, and the computer model was made The paper presents the CFD analysis regarding the influence of the state parameters on the dynamics of carbon dioxide flow inside the ventilation systems. Thus, the state parameters determined in the experimentation area and their introduction into CFD modeling are presented, respectively the establishment of the flow and dispersion model of carbon dioxide in ventilation ducts with high complexity, in the intake, transport and exhaust phases.*

Keywords: *CFD, dispersion, accumulation, exhaust, asphyxiating gas, ventilation*.

1. INTRODUCTION

In order to simulate the dynamics of gas dispersion, specialized programs known as the CFD (Computational fluid dynamics) technique are used as a leading technique. The purpose of the integrated tools that are part of the CFD technique is to reproduce the experimental tests by using specific mathematical devices. Especially in engineering, CFD is at the stage where "problems with complex geometries can be solved with simple physical models and those with simple geometry can be solved with complex physical models". [1, 2]. In order to carry out the CFD simulation of the dynamics of circulation and dispersion of carbon dioxide inside the piping of a

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ventilation installation under the influence of air state parameters, the "experimental system with variable structure for the study of complex industrial ventilation networks" was used as a model. Ventilation systems are complex and can serve several closed premises. In conditions where variable concentrations of carbon dioxide appear untimely in the suction area of the ventilation system, the flow will have a distinct regime, being influenced both by the amount of asphyxiating gas and by air condition parameters. Through the CFD simulation, the virtual image of the complex flow process is obtained with the highlighting of areas in the piping with higher and lower concentrations of carbon dioxide. The results obtained can be used to establish preventive measures for the occurrence of asphyxiating gases such as carbon dioxide, respectively identifying the necessary measures to ensure the safety of workers.

2. ASPECTS RELATED TO THE CFD APPLICATION

CFD technique was used to study the dispersion dynamics of asphyxiating gases with the help of the ANSYS MULTIPHISICS software package.

The ANSYS package allows practically parametric realization and then optimization of any problem, regardless of the type of parameters, the types of finite elements used, the type of analysis, etc. and even using user-declared optimization algorithms. This package contains a series of solvers dedicated to the particularities of analyzing and solving the systems taken into account: mechanical, thermal and stability for solving structural and thermal problems, linear or not; Separate task equivalent to Design Space, with entry-level thermal and structural calculation capabilities; Fluid-structural and mechanical, CFD type, with solutions in the field of fluid mechanics, structural and thermal; Multiphysics, with structural, thermal, electromagnetic (low and high frequency) capabilities, FLOTRAN; Complete solver type CFX or equivalent, for fluid dynamics; Interconnection solver of physical and multiphysics solutions, of bidirectional fluid-structure interactions, with the involvement of multiphysics and CFX type solvers; Solver for fluid dynamics, type Fluent or equivalent; Solver for modeling NOx formations and consumption in combustion systems; Solver for drying and melting processes; Magneto-hydro-dynamic mode; Module for multiphase flows, with particle distribution; Solver for Nonlinear Dynamics of Solids, Fluids, and Gases, and Their Interaction (2D and 3D) [1, 2, 6, 10, 11] ANSYS is a finite element analysis software package widely used in industry and research, in order to simulate the response of multiphysics analyses, giving the user the possibility to combine the effect of two or more physical phenomena.

3. ESTABLISHING THE CONDITIONS FOR EXPERIMENTATION

The experimental system with variable structure for the study of complex industrial ventilation networks consists of a centrifugal fan-motor aggregate and a complex structure of rectangular tubing with dimensions of 300/400 mm. [3, 4, 9,12]

In order to carry out the simulation in a manner as close as possible to the experimental conditions, the topographic elevation of the ventilation installation was carried out within the experimental laboratory, where the experiments were carried out in the laboratory, and the computer model was made [5, 7, 8, 13], figure 1-4.

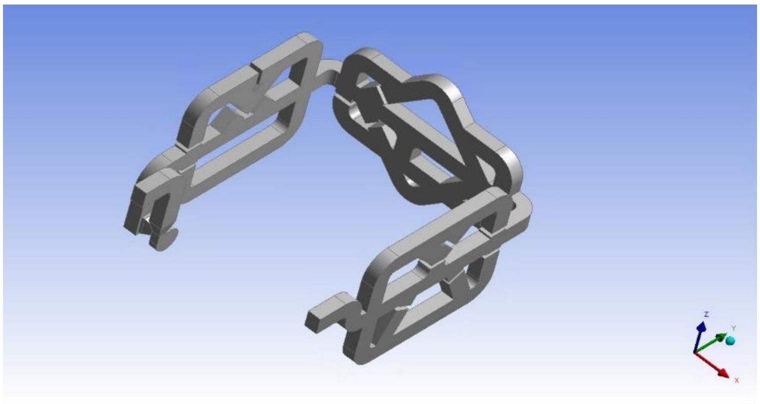

Figure 1. Modeling of the ventilation installation in 3D system

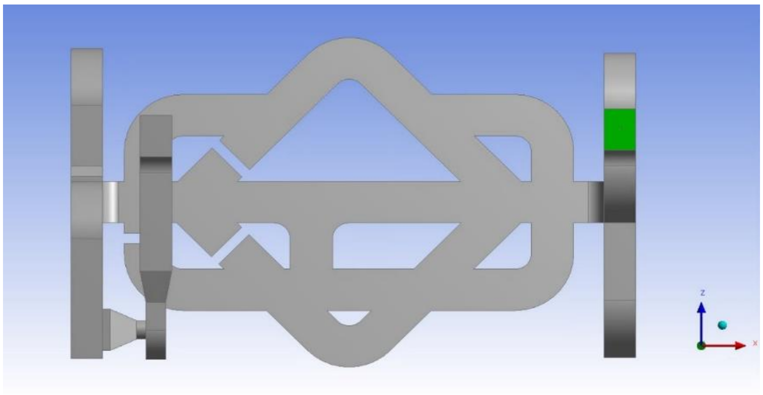

Figure 2. Modeling of the ventilation installation in 2D system with focus on the suction area

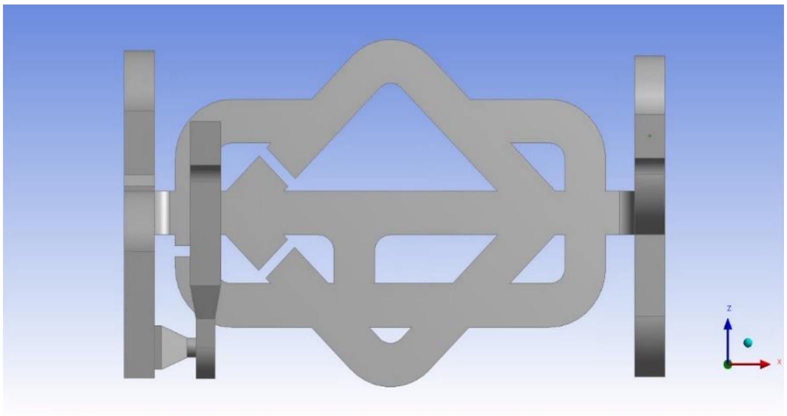

Figure 3. Modeling of the ventilation installation in 2D system with focus on the traffic route

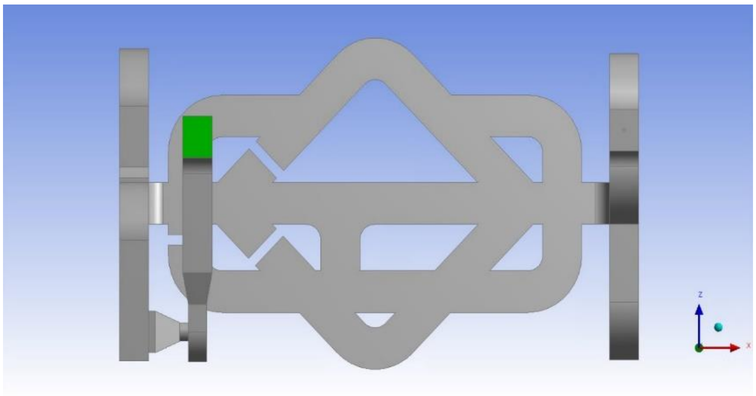

Figure 4. Modeling of the ventilation installation in 2D system with focus on the discharge area

4. THE EXPERIMENT CARRIED OUT WITH THE AXFISIENT GAS

The following aspects were established for modeling:

- The introduced carbon dioxide has a concentration of 100% Vol.;
- The introduction of the gas is carried out at the level of the suction mouth;
- The carbon dioxide discharge is carried out by means of a hose with an internal diameter of 8 mm;
- The flow of gas pumped into the ventilation pipe is 223 l/min;
- The carbon dioxide dispersion phenomenon is carried out at constant pressure;
- Atmospheric pressure, temperature and humidity are those currently encountered at the experimental site;
- Simulation time set at 5 minutes;
- Carbon dioxide concentration of 1000 ppm.

Following the modeling of the dispersion of carbon dioxide inside the ventilation duct, the results of the gas concentration in the right side chain, frontal area, left side chain and exhaust area were obtained, which are presented in table 1.

Table 1. Carbon dioxide concentration results

Modeling results CO_2 concentration / time									
Time (s)	CO_2 (mol/mol)	Time (s)	CO_2 (mol/mol)	Time (s)	CO2 (mol/mol)	Time (s)	CO_2 (mol/mol)	Time (s)	CO_2 (mol/mol)
0	0	60	0,000202606	120	0,000202795	180	0,000202836	240	0,000202849
0,04	9,3858E-11	60,04	0,000202606	120,04	0,000202794	180,04	0,000202836	240,04	0,00020285
0,08	3,29292E-10	60,08	0,000202606	120,08	0,000202794	180,08	0,000202837	240,08	0,000202851
0,12	6,58E-10	60,12	0,000202605	120,12	0,000202793	180,12	0,000202838	240,12	0,000202851
0,16	2,13704E-09	60,16	0,000202604	120,16	0,000202793	180,16	0,000202839	240,16	0,000202851
0,2	6,61724E-09	60,2	0,000202604	120,2	0,000202793	180,2	0,00020284	240,2	0,000202851
…	……..	…..	………	…..	……..	…..	……..	…..	…….
59,4	0,000202599	119,4	0,000202792	179,4	0,000202839	239,4	0,000202851	299,4	0,00020285
59,44	0,000202598	119,44	0,000202793	179,44	0,00020284	239,44	0,000202851	299,44	0,00020285
59,48	0,000202598	119,48	0,000202793	179,48	0,000202841	239,48	0,00020285	299,48	0,000202849

Modeling results CO_2 concentration / time									
Time (s)	CO_2 (mol/mol)	Time (s)	CO_2 (mol/mol)	Time (s)	CO2 (mol/mol)	Time (s)	CO_2 (mol/mol)	Time (s)	CO_2 (mol/mol)
59,52	0,000202597	119,52	0,000202794	179,52	0,000202841	239,52	0,00020285	299,52	0,000202848
59,56	0,000202598	119,56	0,000202795	179,56	0,000202841	239,56	0,000202849	299,56	0,000202848
59,6	0,000202598	119,6	0,000202796	179,6	0,000202841	239,6	0,000202848	299,6	0,000202848
59,64	0,000202598	119,64	0,000202797	179,64	0,000202841	239,64	0,000202847	299,64	0,000202849
59,68	0,000202599	119,68	0,000202798	179,68	0,00020284	239,68	0,000202846	299,68	0,000202849
59,72	0,0002026	119,72	0,000202798	179,72	0,000202839	239,72	0,000202846	299,72	0,00020285
59,76	0,000202602	119,76	0,000202799	179,76	0,000202838	239,76	0,000202846	299,76	0,000202851
59,8	0,000202603	119,8	0,000202799	179,8	0,000202838	239,8	0,000202846	299,8	0,000202852
59,84	0,000202604	119,84	0,000202798	179,84	0,000202837	239,84	0,000202846	299,84	0,000202853
59,88	0,000202605	119,88	0,000202798	179,88	0,000202836	239,88	0,000202847	299,88	0,000202853
59,92	0,000202606	119,92	0,000202797	179,92	0,000202836	239,92	0,000202847	299,92	0,000202854
59,96	0,000202606	119,96	0,000202796	179,96	0,000202835	239,96	0,000202848	299,96	0,000202854
								300	0,000202854

For the dispersion of carbon dioxide inside the ventilation pipe, the gas concentration variation diagram was obtained, figure 5.

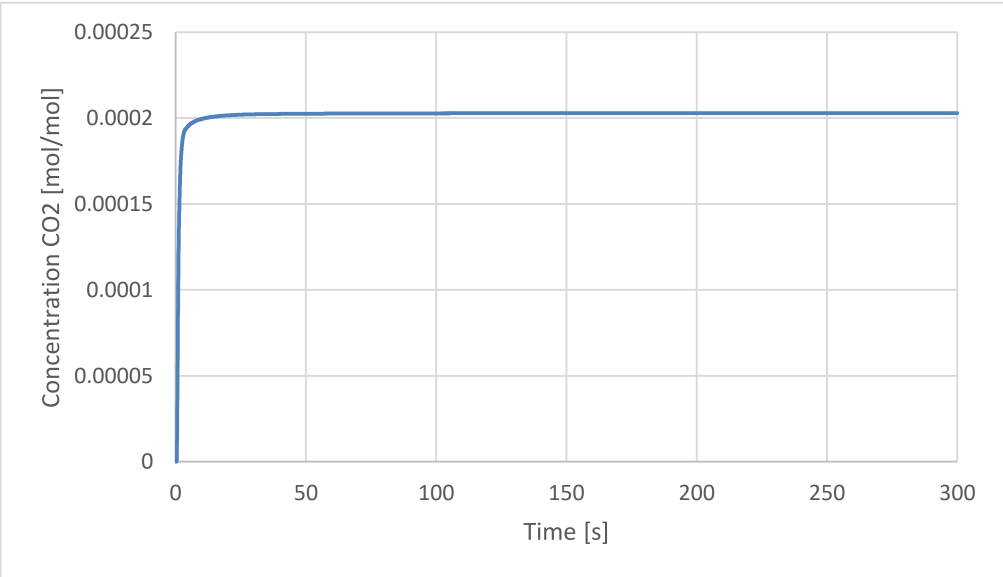

Figure 5. Variation of carbon dioxide dispersion in the ventilation duct

The result of the computer modeling for a simulation time of 5 minutes is presented graphically in figure 6-9.

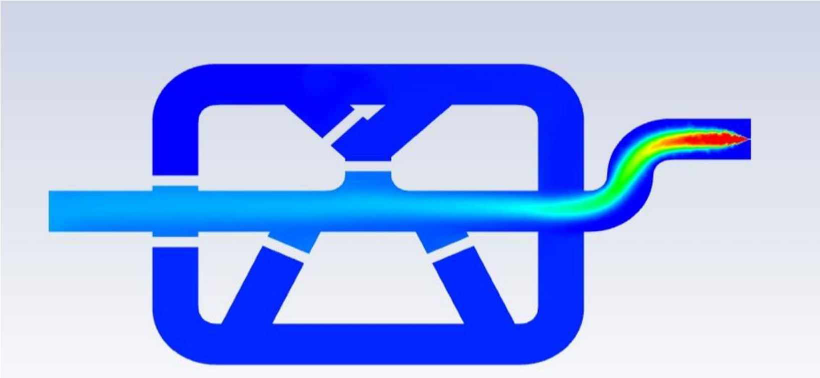

Figure 6. Simulation of carbon dioxide dispersion in the right side chain ventilation pipe

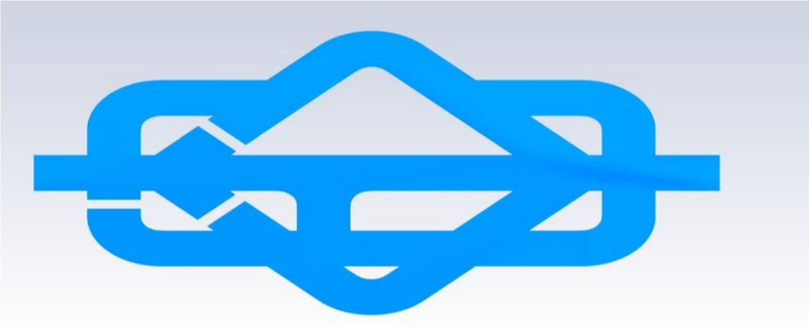

Figure 7. Simulation of carbon dioxide dispersion in the ventilation duct, frontal area

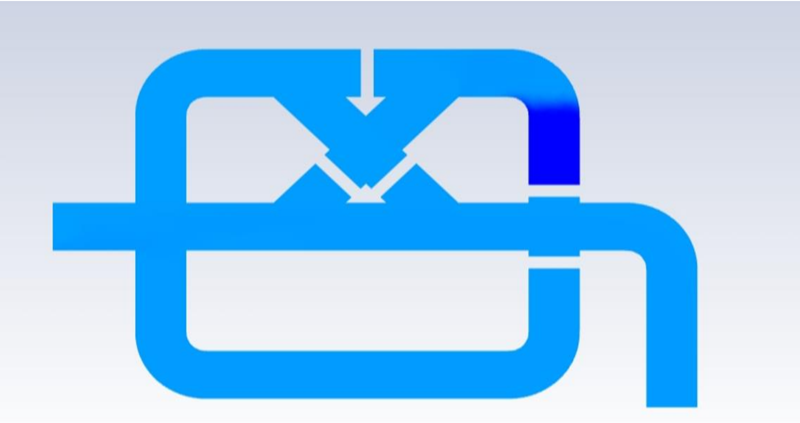

Figure 8. Simulation of carbon dioxide dispersion in the left side chain ventilation pipe

Figure 9. Simulation of carbon dioxide dispersion in the ventilation duct, exhaust area

From the modeling regarding the variation of the air condition parameters inside the industrial ventilation installations through the use of carbon dioxide, CO_2, the following emerges:

- The dispersion process at the level of the industrial ventilation installation in the right side chain is characterized by a variable evolution. Thus, a variation of carbon dioxide concentrations along the flow direction was found. A preferential flow was also found in the middle area, while the upper and lower parts of the right lateral chain do not present significant concentrations of carbon dioxide;
- The dispersion process at the level of the industrial ventilation installation in the frontal area is characterized by a variable evolution. Thus, a variation of carbon dioxide concentrations was found throughout the structure of the frontal area. An equalization of carbon dioxide concentrations was also found on all the branches of the frontal area;
- The dispersion process at the level of the industrial ventilation installation in the left side chain is characterized by a variable evolution. Thus, a variation of carbon dioxide concentrations was found throughout the structure of the left lateral chain. An equalization of carbon dioxide concentrations was also found, at a high level, on all branches of the left lateral chain except for the anterior superior area where the concentration of carbon dioxide is insignificant;
- The dispersion process at the level of the industrial ventilation installation in the left side chain is characterized by a variable evolution. Thus, a variation of carbon dioxide concentrations was found throughout the structure of the left lateral chain. An equalization of carbon dioxide concentrations was also found, at a high level, on all branches of the left lateral chain except for the anterior superior area where the concentration of carbon dioxide is insignificant.

5. CONCLUSIONS

The present work allowed highlighting the following findings:

1. Inside a ventilation installation, the air flow speed must be strong enough both to entrain and direct particles and asphyxiating gases such as carbon dioxide towards the suction mouth and to ensure their continuous transport to the discharge mouth;
2. At the international level, the CFD - computational fluid dynamics technique is used as a top tool in the research field;
3. To study the influence of air condition parameters on asphyxiating atmospheres, the CFD technique was used with the help of the ANSYS MULTIPHISICS software package.
4. The carbon dioxide dispersion process is characterized by a variable evolution;
5. From the modeling regarding the variation of the air state parameters inside the industrial ventilation installations by using carbon dioxide – the concentration of carbon dioxide asymptotically tends towards the value of 205 ppm which it reaches after 10 seconds from the start of the modeling. From this moment the carbon dioxide concentration remains constant until the end of the simulation;
6. The carbon dioxide dispersion process inside the ventilation installation was controlled in 4 areas, namely:
   - The industrial ventilation installation of the right side chain, which also includes the suction mouth;
   - Industrial ventilation installation in the front area;
   - Industrial ventilation installation left side chain;
   - Industrial ventilation installation discharge area.
7. Modeling regarding the variation of air condition parameters inside industrial ventilation installations by using carbon dioxide, CO_2 showed a dispersion phenomenon oriented towards the direction of flow of the introduced gas. The flow of carbon dioxide is characterized by a constant circulation, at higher concentrations, at the level of all chains of the ventilation installation;
8. The concentration of carbon dioxide is maximum in the introduction area, at the level of the suction mouth, gradually decreases by dilution as it moves away from the source, and becomes constant at the level of the chains of the ventilation installation, including the exhaust area.

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CFD SIMULATION OF METHANE DISCHARGE DYNAMICS FROM ENCLOSURES CLOSED

Doru CIOCLEA[1], Ion GHERGHE[1], Florin RĂDOI[1], Adrian MATEI[1]

Abstract: *Anthropogenic activities involve extracting the transformation and use of natural resources. During the process of surface or underground extraction of useful mineral substances, particles or gases appear in the working environment resulting from the removal or natural release from the rock mass. The process of transforming useful mineral substances is carried out on the surface in closed enclosures, usually, and involves the use of complex technological processes. Explosive or toxic gases, mists, dusts or powders may be released into the working atmosphere during these technological processes. Industrial hazards in enclosed spaces are released into the atmosphere for workers' safety reasons. In the event that workers are caught in the event of fire or explosion caused by flammable or explosive substances, morbidity is extremely high. The paper presents the CFD analysis regarding the determination of methane dispersion dynamics during evacuation at a closed enclosure.*

Key words: *CFD, exhaust, dilution, gas dynamics, toxic gas, methane, closed spaces*

1. INTRODUCTION

The CFD technique is widely used to study various physical phenomena including the dispersion of gases in closed, semi-closed or open spaces [1-6]. In order to simulate gases, the CFD technique uses specific mathematical devices such as the equations of Euler, Gromeka - Lamb, Cauchy, Helmholtz, Cauchy-Helmholtz, Navier - Stokes, etc. specific to the laminar flow of real fluids [7-14]. For operability, solving algebraic equations is done using the calculation technique. In the case of turbulent flow of real fluids, semi-physical models are used. The CFD technique is very complex, which is why the simulation time is much longer, sometimes requiring several days to complete the modeling. The simulation of different physical phenomena including gas dispersion can be achieved both experimentally and by CFD technique, the results obtained being sometimes different [6,15]. Due to the complexity of this technique, predictions of the physical effects generated by the flow of fluids can be obtained, even in conditions where in the direction of flow the fluid encounters obstacles, which is why it is extremely useful for establishing the dispersion dynamics of gases and in particular methane in a closed enclosure [16-19]. It is useful to determine the evolution of methane dispersion dynamics both horizontally and vertically because there may be a possibility that at certain points in the enclosure the gas concentrations are higher than the calculated average concentration or even in the

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explosive range in case if an efficient source of ignition is present, the phenomenon of explosion occurs [20,21].

2. DESCRIPTION OF THE TECHNIQUE USED

The CFD technique (computational fluid dynamics) was used to study the dispersion dynamics of explosive, toxic and asphyxiating gases using the ANSYS MULTIPHISICS software package. ANSYS is a finite element analysis software package widely used in industry and research, in order to simulate the response of multiphysics analyzes, offering the user the possibility to combine the effect of two or more physical phenomena (structural, thermal, electrical, magnetic , electromagnetic, electrostatic, fluid flow). The ANSYS package allows practically the parametric realization and then the optimization of any problem, regardless of the type of parameters, the types of finite elements used, the type of analysis, etc. and even the use of user-declared optimization algorithms. This package contains a series of solvers dedicated to the particularities of analysis and solving of the taken into account systems. In order to pre-process the analyzes and post-process their results, the ANSYS multiphysics package has: Fluid dynamics-specific pre-processor (CFX); Post-processor for CFX and Fluent use; Pre- and post-processor specific to the interactions of solids, fluids and gases; Pre- and post-processor specific to fluid dynamics, Fluent type or equivalent; Advanced discretization application, including methods: Cartesian, hex, dominant-hex, multi-zone, prismatic, shell meshing (quad and tri, patch-based and patch-independent), tetra (Delaunay, Octree), T-Grid ; and so on.

3 ESTABLISHING THE EXPERIMENTATION CONDITIONS

In order to establish the dynamics of the explosive gases evacuation, the modeling of the methane dispersion in a closed enclosure was performed with the help of the CFD technique [22]. In order to carry out the simulation in a way as close as possible to the experimental conditions, the topographic survey of the location within the experimental laboratory where the experiments were performed in the laboratory was performed, and the computerized model was made (figure 1).

At the level of the modeled enclosure, 3 sets of points presented in table 1 were established, located at elevations 0.5, 1.5 and 3m, respectively, from the floor (figure 2). Point sets are used to monitor the evolution of gas concentrations during the modeling period.

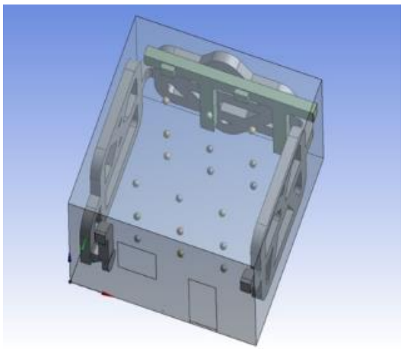

Figure 1. Site modeling

Table 1. Coordinates of control points

	P1A	**P1B**	**P1C**	**P1D**	**P1E**	**P1F**
X_1	1.5	2.8	4.1	1.5	2.8	4.1
Y_1	1.5	1.5	1.5	4.0	4.0	4.0
Z_1	0.5	0.5	0.5	0.5	0.5	0.5
	P2A	P2B	P2C	P2D	P2E	P2F
X2	1.5	2.8	4.1	1.5	2.8	4.1
Y2	1.5	1.5	1.5	4.0	4.0	4.0
Z2	1.5	1.5	1.5	1.5	1.5	1.5
	P3A	P3B	P3C	P3D	P3E	P3F
X3	1.5	2.8	4.1	1.5	2.8	4.1
Y3	1.5	1.5	1.5	4.0	4.0	4.0
Z3	3.0	3.0	3.0	3.0	3.0	3.0

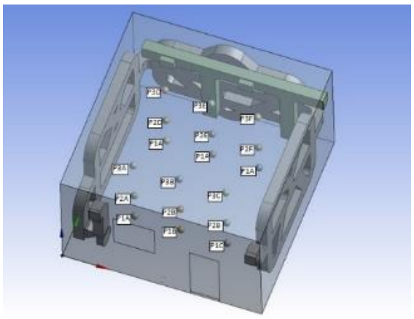

Figure 2. Location of control points

4. CFD MODELING

The following aspects have been established for modeling: The phenomenon of methane dilution is performed under the influence of the complex ventilation system with variable configuration; Atmospheric pressure, temperature and humidity are common at the experimental site; Simulation time set to 10 minutes; The obtained concentrations were given in moll fraction. Following the modeling of the methane dilution dynamics inside the closed enclosure, the results of the gas concentration were obtained at the established control points, on levels 1, 2 and 3, which are presented in tables 2-4.

For the dilution dynamics of methane at the level of the plane of points 1a; 1b; 1c; 1d; 1e; 1f, the gas concentration variation diagram was obtained, figure 3 (On the ordinate we have the methane concentration and on the abscissa the simulation time).

Table 2. Evolution of gas concentrations at control level 1

Time_ Step [s]	**point-1a**	**point-1b**	**point-1c**	**point-1d**	**point-1e**	**point-1f**
0	0.103264906	0.117119052	0.10458108	0.102652751	0.128732815	0.103769146
1	0.10329023	0.108850129	0.055277903	0.102622814	0.129675716	0.10384877
2	0.103303969	0.106760845	0.091397479	0.102586247	0.127238825	0.10389591
3	0.103327513	0.105101921	0.096638404	0.10251008	0.109786779	0.073719583
……	……..	……….	………..	………..	……….	…………
595	0.007219716	0.006981356	0.007257428	0.007901107	0.007117166	0.006032897
596	0.007173329	0.007028449	0.007187636	0.007831185	0.007064248	0.005898532
597	0.007126056	0.007062059	0.007143286	0.007735151	0.007042578	0.005777781
598	0.007099848	0.007062515	0.007124506	0.007635721	0.007052224	0.005680742
599	0.00709736	0.007033651	0.007129042	0.007556941	0.007083377	0.005612289
600	0.007094714	0.00700912	0.007152584	0.00749319	0.007130587	0.005570357

Table 3. Evolution of gas concentrations at control level 2

Time_ Step [s]	**point-2a**	**point-2b**	**point-2c**	**point-2d**	**point-2e**	**point-2f**
0	0.107908793	0.108946949	0.109231547	0.105630122	0.110063575	0.105429344
1	0.107965246	0.109063163	0.109064467	0.105711222	0.109451689	0.105470374
2	0.108014077	0.109213136	0.109159634	0.105777934	0.109768778	0.105466299
3	0.108067788	0.109365426	0.109297954	0.105839886	0.110637046	0.105409436
………	……….	…………	………….	…………	………….	…………
595	0.006625173	0.00722769	0.0076649	0.007001293	0.006815863	0.006462997
596	0.006609756	0.007207497	0.007667487	0.006978409	0.006860486	0.006401444
597	0.006576003	0.007186571	0.007665758	0.006919586	0.006908474	0.006295526
598	0.006538277	0.007163034	0.007661793	0.006872375	0.006961948	0.006272042
599	0.00653428	0.007112246	0.007659428	0.006855388	0.007020256	0.006324986
600	0.006573011	0.007039017	0.007658704	0.006857932	0.007077022	0.006361958

Table 4. Evolution of gas concentrations at control level 3

Time_ Step [s]	**point-3a**	**point-3b**	**point-3c**	**point-3d**	**point-3e**	**point-3f**
0	0.110614777	0.111939438	0.114088058	0.108064927	0.107473366	0.109331489
1	0.11057087	0.112058096	0.114391692	0.108173609	0.107610598	0.109413065
2	0.110592514	0.11215391	0.114944145	0.108303808	0.107737549	0.10933464

Time_ Step [s]	point-3a	point-3b	point-3c	point-3d	point-3e	point-3f
3	0.110666528	0.11216981	0.115227722	0.108396299	0.107861705	0.109550916
………	………….	………….	………….	………….	………….	…………..
595	0.007435505	0.007157629	0.00774138	0.005727235	0.007022157	0.00770551
596	0.007387263	0.00712227	0.007740417	0.005590207	0.006971066	0.007680275
597	0.007319023	0.007031656	0.007735562	0.005652408	0.006950928	0.007648815
598	0.007226944	0.007057972	0.007723487	0.005853001	0.006967292	0.007611417
599	0.00713463	0.007231701	0.007699216	0.005951717	0.006994335	0.007570884
600	0.007084446	0.007303037	0.007669889	0.005910815	0.007015971	0.007530302

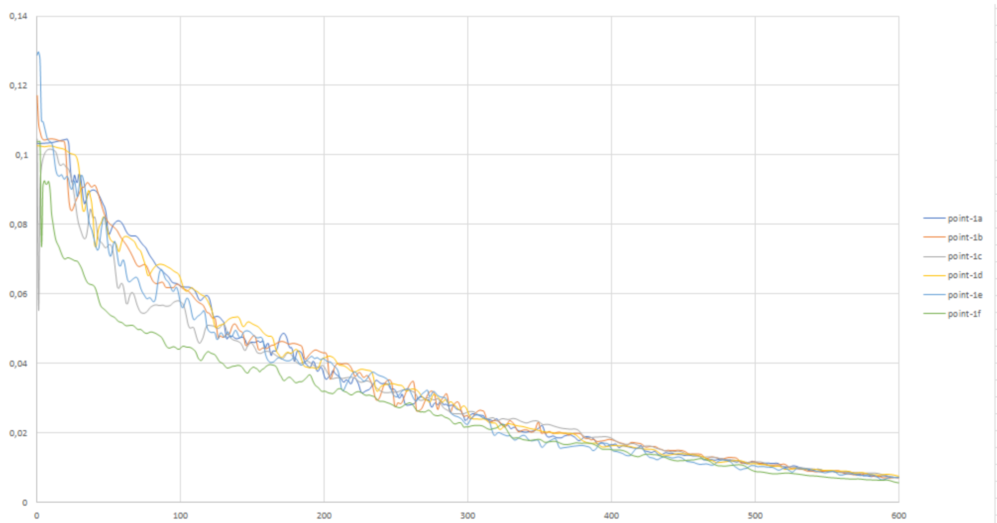

Figure 3. Dynamics of methane dispersion at level 1

For the dilution dynamics of methane at the level of the plane of points 2a; 2b; 2c; 2d; 2e; 2f, the gas concentration variation diagram was obtained, fig. 4 (On the ordinate we have the methane concentration and on the abscissa the simulation time).

For the dilution dynamics of methane at the level of the points 3a; 3b; 3c; 3d; 3e; 3f, the gas concentration variation diagram was obtained, figure 5 (On the ordinate we have the methane concentration and on the abscissa the simulation time).

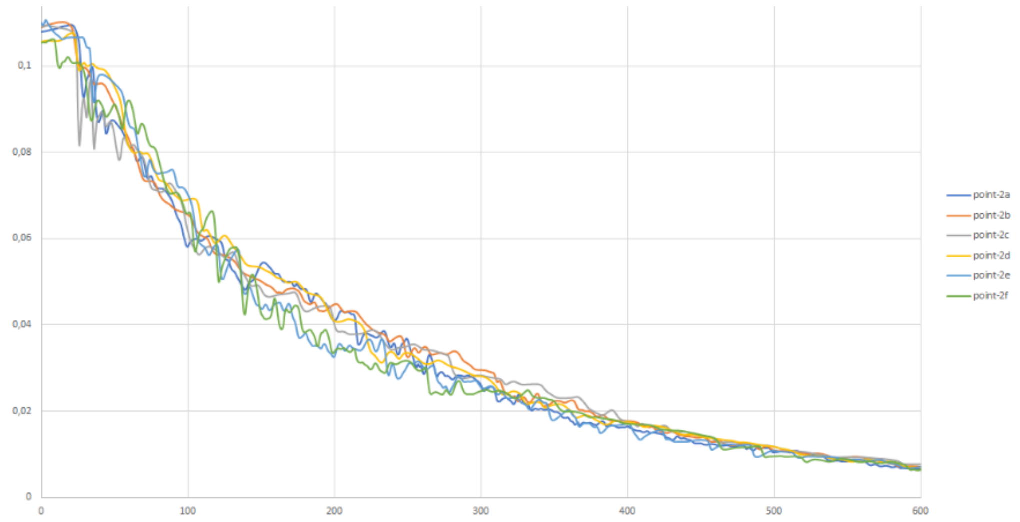

Figure 4. Dynamics of methane dispersion at level 2

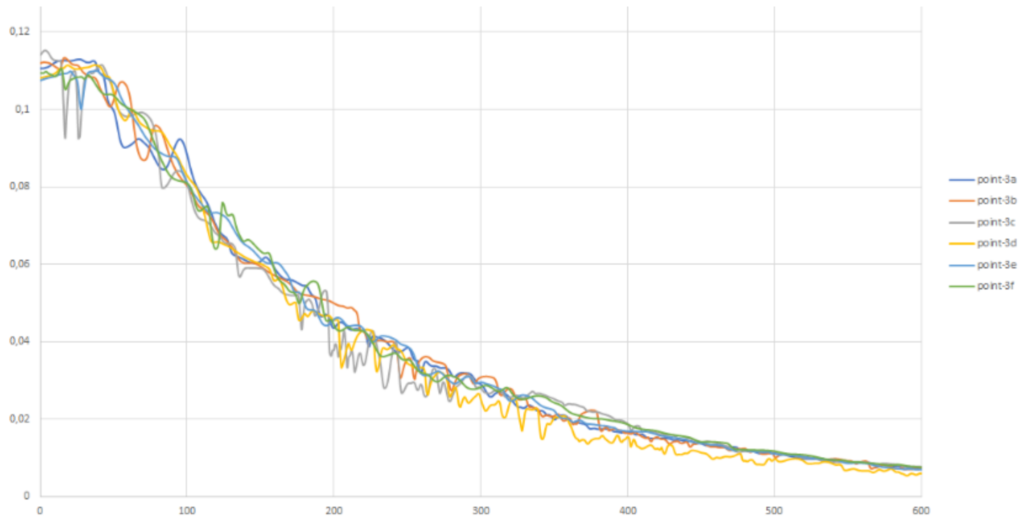

Figure 5. Dynamics of methane dispersion at level 3

The result of the computer modeling for a simulation time of 10 minutes is shown graphically in figures 6 – 11 (where the introduction of methane in the lower left part has stopped and the rectangles on the right side represent other equipment present in the experiment chamber. The yellow color represents the methane and the blue one the atmospheric air).

In figure 6 It is observed that at time 0, when the methane introduction has been stopped, the high concentration fluid is still present at the floor and on the opposite wall, homogeneous in the rest of the volume of the enclosure. Phase 0 shows the maximum gas dispersion at the enclosure and captures the moment between stopping the introduction of the methane jet and starting the ventilation system.

In figure 7 it is observed that 10 s. from the start of modeling, the methane jet introduced in the floor disappears. Under the influence of the ventilation system, the cloud of homogeneous gas is directed towards the suction openings. In the vicinity of the suction nozzles, an inhomogeneous area is observed in which the dilution of methane due to fresh air is visible. The dilution of the gas at the enclosure level is in the incipient evolution phase.

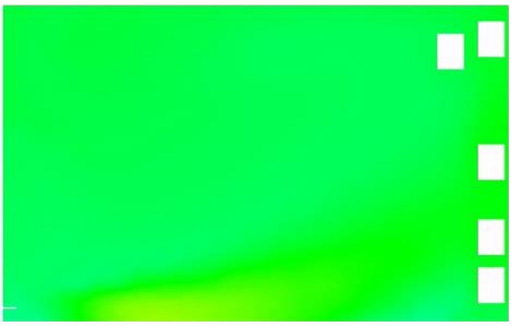

Figure 6. Methane dispersion at the start of the ventilation system

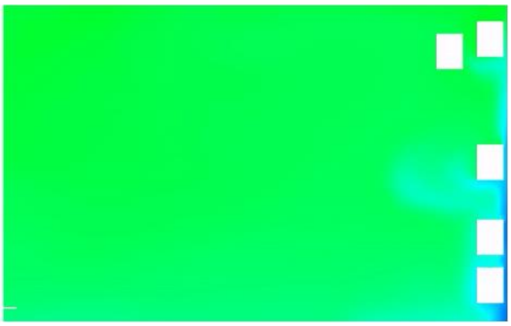

Figure 7. Evolution of methane dilution 10 s after starting the ventilation system

In figure 8 it is observed that 20 s from the start of the modeling regarding the dilution and evacuation of methane accumulated in a closed enclosure, the gas cloud with higher concentration located in the area of the access wall is displaced and diluted inhomogeneously and moves mainly to the ceiling suction mouths.

In the area of the floor and the suction nozzle the gas cloud is visibly diluted. The dilution of the gas at the enclosure level is in the incipient evolution phase.

In figure 9 it is observed that 30 s. from the start of the modeling, the gas cloud with higher concentration located in the central area is dislocated and diluted inhomogeneously mainly at the floor and moves relatively laminarly towards the suction mouths. There are areas of accentuated dilution in the floor area. The gas dilution at the enclosure is in the reduced dilution phase.

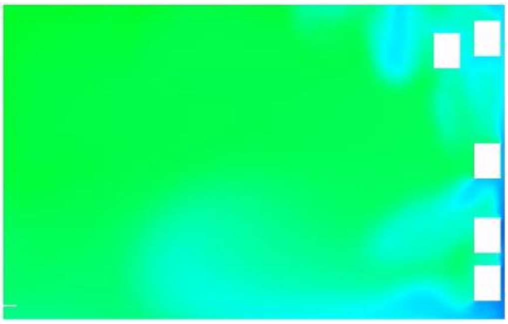

Figure 8. Evolution of methane dilution 20 s after starting the ventilation system

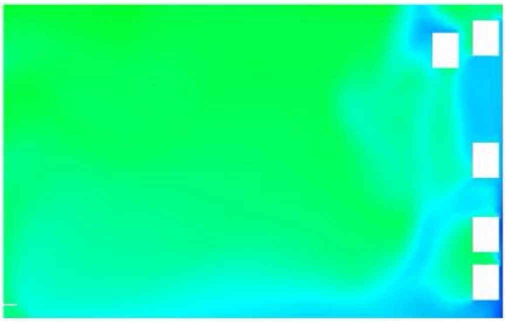

Figure 9. Evolution of methane dilution 30 s after starting the ventilation system

At 40 s from the start of the modeling, the gas cloud with homogeneous concentration has an irregular distribution at the enclosure and moves relatively evenly towards the suction mouths. In the area of the entrance wall, at the floor, respectively in the area of the suction mouths, areas with accentuated dilution appear. The gas dilution at the enclosure is in the lower average development phase.

After 50 s, from the start of modeling, the gas cloud with relatively homogeneous concentration has an uneven distribution at the enclosure, mainly at the ceiling, and moves relatively evenly towards the suction mouths. In the area of the entrance wall, and especially in the floor and in the area of the mouth openings, areas with accentuated dilution appear. The gas dilution at the enclosure is in the lower average development phase.

At 1 min, from the start of modeling, the gas cloud with relatively homogeneous concentration has an uneven distribution at the enclosure being located mainly on the ceiling, and moves relatively evenly towards the suction mouths. In the area of the entrance wall, at the floor, respectively in the area of the suction mouths, areas with accentuated dilution appear. The gas dilution at the enclosure is in the middle development phase.

After 2 min, from the start of the modeling, the gas cloud was massively diluted in almost the entire volume of the enclosure. A volume of gas with a relatively homogeneous concentration is confined only to the ceiling with an uneven distribution and moves relatively evenly towards the suction mouths. In the area of the floor, in the middle and in the upper area, respectively in the area of the suction mouths, areas with massive dilution appear. The gas dilution at the enclosure is in the upper lower development phase.

At 3 min. respectively 4 min. since the start of modeling, the gas cloud has been massively diluted in almost the entire volume of the enclosure and moves relatively unevenly towards the suction mouths. Areas with total dilution appear in the area of the suction mouths. The gas dilution at the enclosure is in the upper middle development phase.

In figures 10 and 11 it is observed that at 5 min. respectively 6 min. since the start of the modeling, the gas cloud has been diluted almost completely and evenly throughout the enclosure volume and moves evenly towards the suction mouths. The gas dilution at the enclosure is in the almost total development phase.

Figure 10. Evolution of methane dilution at 5 min. from the start of the ventilation system

Figure 11. Evolution of methane dilution at 6 min. from the start of the ventilation system

5. DISCUSSIONS

The following observations can be deduced from the modeling of the dilution and evacuation of explosive gases indoors using methane CH4:

The process of diluting and discharging methane gas indoors was controlled in 18 points evenly distributed on three distinct levels, namely:

- Lower level 1 consisting of 6 control points located at 0.5 m from the floor;
- Level 2 average consisting of 6 checkpoints located at 1.5 m from the floor;
- Upper level 3 consisting of 6 control points located at an altitude of 3 m from the floor.

The dispersion process at the lower level 1 is characterized by a variable evolution. Thus, a variation of the specific gas concentrations for turbulent flow at all control points was found in the first part followed by a relatively homogeneous flow in the second part of the dilution process. The gas concentrations at point 1f show a slightly different variation throughout the process;

The dispersion process at medium level 2 is characterized by a variable evolution. Thus, a variation of the specific gas concentrations for turbulent flow at all control points was found in the first part followed by a relatively laminar flow in the second part of the exhaust dilution process;

The dispersion process at the upper level 3 is characterized by a variable evolution. Thus, a variation of the specific gas concentrations for turbulent flow at all control points was found in the first part followed by a laminar flow in the second part of the dilution process. The gas concentrations at the level of point 3d show a slightly different variation in the last part of the process;

The closed gas dispersion and progressive dilution gradient at the enclosure, Gd, showed a variable evolution depending on the position of the control points in the plan as follows:

- The gas dispersion and progressive dilution gradient, Gd, at the lower level 1 showed values included between 5.709 and 7.296% Vol. / h;
- The gradient of dispersion and progressive dilution of the gas, Gd, at the average level 2 showed values between 5,926 and 6,179% Vol. / h;
- The gradient of dispersion and progressive dilution of the gas, Gd, at the upper level 3 showed values between 6.027 and 6.385% Vol. / h.

Modeling the dilution and discharge of methane from the closed enclosure showed a relatively uniform dilution phenomenon oriented towards the suction mouths. The methane flow has the shape of a relatively homogeneous cloud with the location of high concentrations at the ceiling.

The gas flow moves under the depression of the ventilation system from the entrance wall area relatively evenly to the suction and discharge area.

The methane concentration in the initial phase is maximum in the middle and upper area, and becomes relatively uneven and low in the outlet area at the mouth.

Methane has a medium dilution capacity by moderately decreasing gas concentrations during the exhaust process.

6. CONCLUSIONS

At the international level, the CFD - computational fluid dynamics technique is used as a leading tool in the field of research;

For the study of the dilution dynamics of explosive gases, the distribution of methane concentrations during the evacuation in a closed enclosure was performed using the CFD technique;

The dispersion process at the lower level 1 is characterized by a variable evolution. Thus, a variation of the specific gas concentrations for turbulent flow at all control points was found in the first part followed by a relatively homogeneous flow in the second part of the dilution process. The gas concentrations at point 1f show a slightly different variation throughout the process;

The dispersion process at medium level 2 is characterized by a variable evolution. Thus, a variation of the specific gas concentrations for turbulent flow at all control points was found in the first part followed by a relatively laminar flow in the second part of the exhaust dilution process;

The dispersion process at the upper level 3 is characterized by a variable evolution. Thus, a variation of the specific gas concentrations for turbulent flow at all control points was found in the first part followed by a laminar flow in the second part of the dilution process. The gas concentrations at the level of point 3d show a slightly different variation in the last part of the process;

The closed gas dispersion and progressive dilution gradient at the enclosure, Gd, showed a variable evolution depending on the position of the control points in the plan as follows:

- The gas dispersion and progressive dilution gradient, Gd, at the lower level 1 showed values included between 5.709 and 7.296% Vol. / h;
- The gradient of dispersion and progressive dilution of the gas, Gd, at the average level 2 showed values between 5,926 and 6,179% Vol. / h;
- The gradient of dispersion and progressive dilution of the gas, Gd, at the upper level 3 showed values between 6.027 and 6.385% Vol. / h.

Modeling the dilution and discharge of methane from the closed enclosure showed a relatively uniform dilution phenomenon oriented towards the suction mouths;

Methane has a medium dilution capacity due to moderate decreases in gas concentrations during the exhaust process.

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THE USE OF THERMAL IMAGING TECHNOLOGY IN INTERVENTION AND RESCUE ACTIONS IN TOXIC, FLAMMABLE AND EXPLOSIVE ENVIRONMENTS

Cosmin ILIE[1], George Artur GĂMAN[2], Andrei GIREADĂ[3], Izabella KOVACS[4]

Abstract: *The degree of success of an intervention and rescue operation in toxic / explosive / flammable environments can be most correctly quantified by the number of injured persons surprised by the event being intervened, who are identified, resuscitated and safely transported to the nearest health facility/ first aid point. Unfortunately, in most of the cases, the area where the research is carried out is more or less accessible, due to the inundation with smoke, toxic or explosive gases or the lack of visibility. For this reason, we most often witness an oversized consumption of specific rescuers' resources in an attempt to identify and locate accident victims in areas without visibility or with a dangerous atmosphere. The application of thermal imaging technology allows the location of victims of industrial events in which toxic / explosive / flammable gases are generated or in areas without visibility, with the aim of an effective rescue operation, with reduced costs and risks, both for the injured and for the rescuers who intervene in such areas.*

Key words: *Thermal imaging, intervention and rescue, toxic/explosive/flammable environments.*

1. INTRODUCTION

Human protection in the work process aims to eliminate and/or reduce the potential causes of injury, this can be achieved by eliminating and/or reducing risks.

At the international level, in the field of rescue actions from toxic / explosive / flammable environments, the thermal imaging technique is used to locate possible victims, identify fire zones for the development of rescue teams' intervention actions under increased security conditions.

The need to identify and assess professional risks in the case of interventions by rescue teams in smoky environments is an important element in establishing the way of action of intervention and rescue formations [1].

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For this purpose, intervention and rescue teams in toxic / explosive / flammable environments with/or without smoke must know the rules and work procedures so that:

- identify dangers and appreciate the priority and importance of professional risk assessment;
- to have the necessary knowledge to eliminate, reduce or avoid the risk;
- to intervene in the causal process of dangerous incidents, work accidents in order to break the chain of development of these categories of risks.
- to use modern intervention equipment in hostile environments.

All objects emit infrared energy (heat) as a function of their temperature. The infrared energy emitted by an object is known as its heat signature. In general, the hotter an object is, the more radiation it emits. A thermal imager (also known as a thermal camera) is essentially a heat sensor that is capable of detecting tiny differences in temperature. The device collects the infrared radiation from objects in the scene and creates an electronic image based on information about the temperature differences. Because objects are rarely precisely the same temperature as other objects around them, a thermal camera can detect them and they will appear as distinct in a thermal image.

This paper deals with the application of the thermal imaging technique in the rescue activity by a specialized team in a training ground specially created for this purpose.

The aim of the work is to later allow the introduction of this technique in the Rescue Teams Intervention Regulation, given the good results provided by thermal imaging, which leads to the improvement of the security status of the teams involved in the intervention in toxic/explosive / flammable environments [2].

2. PRINCIPLES OF THERMAL IMAGING

The degree of success of a rescue operation in toxic/flammable/explosive environments can be most accurately quantified by the number of injured persons surprised by the event being intervened who are identified, resuscitated and transported safely to the nearest hospital unit/point of care of first aid.

Unfortunately, in most of the cases, the area where the research is carried out is more or less accessible, due to the inundation with smoke, toxic or explosive gases or the lack of visibility. For this reason, we most often witness an oversized consumption of specific rescuers' resources in an attempt to identify and locate accident victims in areas without visibility or with a dangerous atmosphere.

The application of thermal imaging systems allows the location of victims of industrial accidents resulting in the generation of toxic/flammable/explosive gases or in areas without visibility, with the aim of an effective rescue operation, with reduced costs and risks, both for the injured and for the rescuers who intervene in such areas [3].

Thermal imaging or infrared visualization is a technique by which a camera (or scanner) detects and displays a map of the intensity of radiation in a domain of the electromagnetic spectrum. The term thermal imaging defines the image obtained by the thermal camera and is used especially in military applications, civil surveillance or in the interventions of fire brigades.

Thermal imaging can be used for:

- administration of distribution networks (water, heat, gas, pipelines, etc.); detection and location of networks located either on the ground surface or underground; heat distribution analysis; diagnoses; spotting defects; accident prevention; line insulation quality control.

- tracking the heat losses of the buildings: recording the heat leaks through the roofs and through the walls of the buildings, surface photography of urban concentrations.

- monitoring waste heaps, garbage pits, chemical substance tanks, contaminations, ecological loads.

- research in geology, detection of tectonic deformations, contaminations.

- monitoring of hydropower installations, dams; identifying the degree of water pollution; identifying the sources of water pollution.

- climate analysis (monitoring of urban agglomerations on tropical days).

- identification of underground constructions, archaeological sites, abandoned mines.

The detector of the thermal imaging camera measures the object's electromagnetic radiation in the infrared range. This range can be expressed numerically in the wavelength range between 0.75 µm and 1 mm.

The map obtained by thermographic photography is influenced by the characteristics of the observed object and the characteristics of the environment in which it is located. That is why it is necessary to determine the objectives that will be subject to observation and the method used during the analysis. Thermography can be used to monitor the manifestations of thermal contrast [4].

Thermographic photography is restricted by the meteorological conditions in which the measurements take place. Clouds and their shadows have a negative influence on thermography, as does wind with a speed greater than 3m/s, high soil humidity, in some applications even vegetation or direct solar radiation.

Thermal imaging is a modern, high-performance technique that allows the visualization and generation in real time of thermal maps ("thermal images", thermograms) of the biological or technical systems under investigation. To carry out the thermal scanning activity, specialized equipment called thermovision / thermography cameras are used, similar in size and appearance to the well-known video cameras in everyday life.

Thermal imaging is a method of visualizing objects from the point of view of infrared radiation (IR) emitted by them and not from that of visible radiation that can be detected without any difficulty by the human eye. In the usual situation, man can see the surrounding objects due to the light reflected by them. The human eye has the ability to see a narrow portion of the electromagnetic spectrum, called "visible".

The human eye does not have the ability to see the rest of the electromagnetic spectrum, so neither does the spectrum area that includes IR radiation. However, it has been known for a very long time that any body with a temperature higher than 0K emits infrared energy. The primary source of IR radiation is the heat of bodies. IR energy is generated by the vibration and rotation of atoms and molecules in any biological or technical system. The laws on which thermal imaging is based are Planck's Law, which introduced the hypothesis of energy quanta and established a formula for the spectral density of a body's emission that verified the experimental data in the entire frequency range, the Stefan - Boltzmann Law, which established the connection between the integral energy emittance of the body and its absolute temperature and the Wien Displacement Law, which established the connection between the body temperature and the wavelength of the maximum spectral density of the emittance.

The physical-mathematical foundation having been established, the practical utility in the present field was the fact that by measuring the infrared radiation emitted by an object, its temperature can be estimated with excellent precision. The higher the temperature of the object, the more intense the infrared radiation produced. The human body, at its normal temperature, radiates in the infrared range around the wavelength of 10mm. Although we cannot see in the infrared, we are surrounded by this type of radiation every day. Although the eyes are unable to see outside the visible spectrum, the nerves in the epidermis allow our body to feel this radiation in the form of heat [5].

The need to generate thermal maps and images that can be interpreted in various fields of science or everyday life has led to an increase in the interest of some companies in the development of special equipment to expand the human field of vision and in the field of infrared radiation. Thus, thanks to new technologies, thermal imaging and thermography cameras have been manufactured that allow the visualization of IR energy radiated, transmitted and reflected by biological or technical systems, the final result being the visualization of the temperature (temperatures) at the level of the measured object.

The detector structures used in non-contact thermometry, thermovision and thermography work in the infrared portion of the electromagnetic spectrum, which includes radiation with a wavelength between 0.78mm and 1000mm. The IR region can be divided into three subregions: near IR (0.78 - 3 m), mid IR (3 - 30mm) and far IR (30 - 300mm).

3. DRAGER UCF 9000 THERMAL IMAGING CAMERA

The Drager UCF 9000 thermal imaging camera is a thermal imaging camera and a digital camera combined in one (Figure 1). This ensures equipment even for complex tasks – from firefighting operations and activities involving hazardous substances in the Ex 1 zone to monitoring and documenting training courses.

Drager UCF 9000 has a compact structure. All functions can also be operated with the hand holding the camera. Buttons and keys are quickly selected with the thumb or forefinger. With its robust support, the UCF is at your fingertips even when walking on all fours.

The Drager UCF 9000 can capture video and individual photos not only of displayed thermal images, but also of actual digital images. With this option, a real-time recording of real operations and training situations can be made and can be evaluated on the screen on the spot with the playback function [6].

Drager UCF 9000 has eight image playback modes: fire mode (fighting fires), People mode (search and rescue), thermal scanning mode (searching dangerous areas), open spaces mode (searching for people outside), dangerous substance mode (detecting leaks and level indicators), scan mode (searching for heat sources), normal image mode (video camera).

Figure 1. Drager UCF 9000 thermal imaging camera

The basic functions of the Drager UCF 9000 thermal imaging camera are the following:

- The laser indicator, the indicator is used to mark the heat sources or to display the filling level of the tanks.
- Image capture function, look around corners and freeze the image to assess the situation.
- Extended dynamic range, is used to look around corners and to stop the image to assess the situation.
- Extended dynamic range, clearly detects people and objects even near fires.

The advantages of using the Drager UCF 9000 thermal imaging camera are the following: intuitive use, easy and safe handling even in the most difficult conditions, display brightness is automatically adjusted according to the environment, status information is easy to read, modern lithium batteries -ion ensures an operating range of approximately 4 hours, automatic standby mode for longer battery life, different mounting options (neck band or retractable strap), extensive range of accessories (carrying case, set of installation in a vehicle, tripod, etc.)

Even when visibility is also low, the Drager UCF 9000 will ensure optimal image quality and detailed accuracy. With the help of the 384 x 288 pixel sensor, the camera ensures an extremely high resolution and thus offers a very high level of detail. Its 57° (horizontal) field of view will ensure an extremely comprehensive picture of the situation. To enlarge the image even more, there is the possibility to use the 4x zoom in addition to the 2x.

If the recording capacity of approx. 2 hours is finished, the black box of the thermal imaging camera guarantees the further use of thermal imaging videos. If the memory is fully charged, the camera will record over the beginning of the recording. Continuous recording is automatic.

4. CASE STUDY IN THE TRAINING GROUND

In order to highlight the usefulness of the application of thermal imaging in the activity of intervention and rescue in toxic / explosive / flammable environments, some examples are presented by using a Drager-type camera in a Training Range where various simulations of some interventions encountered in reality can be performed [7].

Several situations are presented in which two rescuers simulate various activities (normal walking, exerting effort on ergometers, locating the victim near an energy source, moving in closed spaces), in which, through the thermal imaging technique, the possibility is highlighted that in the case possible sources of fire can be identified for various accidents, the monitoring of people moving through dangerous environments as well as the identification of victims surprised by the occurrence of certain events (fire, explosions, etc.) [8].

Thus we have the following situations:

- simulating movement by using a conveyor belt (Figure 2).

Figure 2. Simulating movement by using a conveyor belt

- effort on ergometers (Figure 3).

Figure 3. Effort on ergometers

- location of the victim (Figure 4).

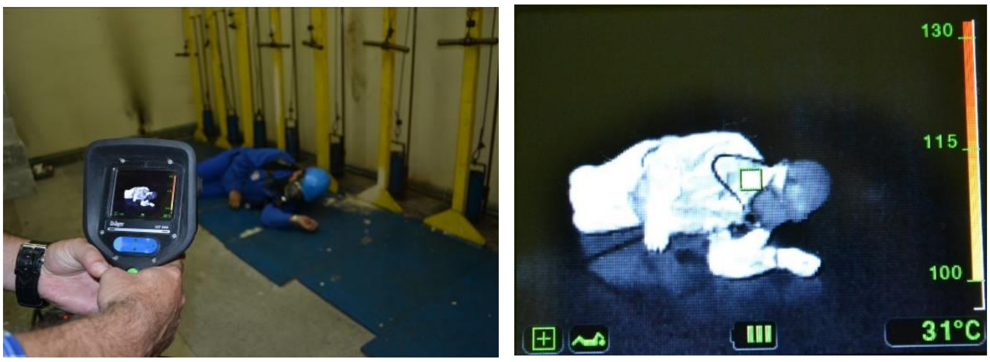

Figure 4. Location of the victim

- identification of the fire source with the possible victim (Figure 5).

Figure 5. Identification of the fire source with the possible victim

- identification of the person in closed spaces (Figure 6)

Figure 6. Identification of the person in closed spaces

Following the tests carried out in the training ground, it was demonstrated that by means of the thermal imaging technique it is possible to identify a person who carries out his activity in various working environments, both in motion and in a static state, and also possible sources of heat that can at some point become potential sources of initiation of explosive atmospheres [9].

5. CONCLUSIONS

The advantages of using the Drager UCF 9000 thermal imaging camera are the following: intuitive use, easy and safe handling even in the most difficult conditions, display brightness is automatically adjusted according to the environment, status information is easy to read, modern lithium batteries -ion ensures an operating range of approximately 4 hours, automatic standby mode for longer battery life, different mounting options (neck band or retractable strap), extensive range of accessories (carrying case, set of installation in a vehicle, tripod, etc.)

The use of thermal imaging technology by the intervention and rescue formations presents the advantage of creating the perspective of a rapid localization, with a maximum degree of precision, of the victims of events resulting in the generation of toxic/explosive atmospheres, with direct implications on the chances of survival of the injured and the individual security of the members of the rescue formations.

The use of thermal imaging technology eliminates unnecessary trips to areas with a high risk of injury in order to search for victims, locating them accurately.

Thermal imaging technology reduces the financial effort borne by the economic agent by making technological flows and productive infrastructure unavailable for a longer period of time.

The use of thermal imaging technology allows the transmission of information in real time to a command center, a fact that allows increasing the operativeness in the rescue activity by identifying optimal intervention solutions.

6. ACKNOWLEDGEMENTS

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Annals of the University of Petrosani, Mining Engineering, 25 (2024)

EXPERIMENTAL MODEL FOR HYDROGEN EXPLOSION DYNAMICS ANALYSIS APPLYING AN AIR BUFFER CHAMBER TO INVESTIGATE THE CHANGE OF PROPAGATION DIRECTION

Ligia Ioana TUHUT[1], Daniel Gheorghe FLOREA[2], Emilian GHICIOI[3]

Abstract: *Hydrogen explosions pose significant safety risks, necessitating detailed experimental studies to understand their dynamics and develop effective mitigation strategies. This paper presents the construction and testing of an experimental stand designed to study hydrogen explosions in a square spiral configuration comprising four interconnected chambers, with the capability of modifying the propagation direction. The initial experiments involved introducing hydrogen into all the chambers to observe the explosion dynamics in a uniform hydrogen environment. In this particular experiment, a novel approach was tested by introducing hydrogen into the first and third chambers, while the second and fourth chambers were filled with clean air. This new configuration aimed to investigate the effects of alternating hydrogen and air-filled chambers on the explosion's behavior. The experimental results were quite unexpected and provided new insights into the direction of explosion propagation and the effectiveness of the sealing methods used. The findings highlighted the complexity of hydrogen explosions in mixed environments and underscored the importance of design of enclosures in influencing the explosion dynamics. These results have significant implications for safety protocols and the design of systems intended to manage hydrogen explosions, offering a deeper understanding of the variables that affect explosive behavior in interconnected chamber setups.*

Key words: *hydrogen, explosion, experimental, ignition, test*

1. INTRODUCTION

Hydrogen explosions present a considerable safety hazard in various industrial and research settings. The unique properties of hydrogen, such as its low ignition energy, wide flammability range, and high diffusivity, make it a particularly challenging substance to manage. Consequently, understanding the dynamics of hydrogen explosions and developing effective mitigation strategies are critical for ensuring safety and minimizing the risks associated with hydrogen use. This paper contributes to this effort by detailing the construction and testing of an experimental stand designed to study hydrogen explosions within a square spiral configuration comprising four interconnected chambers, using Schlieren techniques.

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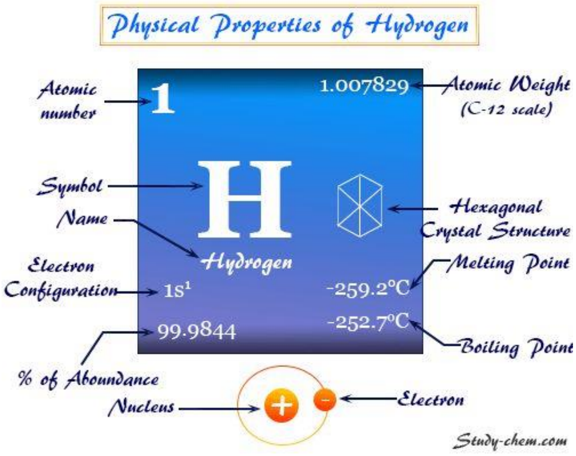

Figure 1. Physical properties of hydrogen

Significant research has been conducted to understand the behavior of hydrogen explosions in various configurations and environments. Early studies have been focused on the fundamental properties of hydrogen combustion, highlighting its rapid combustion kinetics and the potential for detonation under certain conditions. These foundational studies laid the groundwork for more applied research, which seeks to understand hydrogen explosions in more complex geometries and in the presence of various obstacles and confinement structures.

Recent studies have continued to delve into the dynamics of hydrogen explosions. For example, Wang et al. (2018) explored the effects of pressure and temperature on the explosion characteristics of hydrogen-air mixtures, providing insights into the conditions that favor deflagration over detonation. [1]

The configuration of the environment in which hydrogen is introduced plays a significant role in the explosion dynamics. Studies by Hu et al. (2017) have demonstrated that complex geometries, such as interconnected chambers, can lead to unexpected and sometimes counterintuitive explosion behaviors. [2] Their work showed that varying chamber sizes and interconnections significantly influence the flame propagation speed and pressure development during an explosion.

Research into hydrogen explosions in mixed environments, where hydrogen and other gases such as air are present in different regions, has provided valuable insights into the propagation mechanisms. Liu et al. (2019) conducted experiments with alternating hydrogen and air-filled sections in a test apparatus, revealing the impact of gas stratification on explosion propagation and intensity. Their findings emphasize the need to consider mixed gas environments in safety analyses and the development of mitigation strategies. [3]

Despite the extensive body of research, significant gaps remain in our understanding of hydrogen explosion dynamics in highly controlled, complex geometries such as the square spiral configuration explored in this study. Specifically, the effects of alternating hydrogen and air-filled chambers on explosion behavior have not been thoroughly investigated. The experimental stand designed for this research offers a novel approach to studying these effects, with the capability to modify the direction of propagation and analyze the resulting explosion dynamics.

The primary objective of this study is to investigate the dynamics of hydrogen explosions in a square spiral configuration with four interconnected chambers. By introducing hydrogen into different combinations of chambers and observing the explosion behavior, this research aims to provide new insights into the influence of chamber configuration on explosion dynamics. Additionally, the study seeks to evaluate the effectiveness of sealing methods used in the experimental setup and their impact on explosion propagation.

2. EXPERIMENTAL SETUP AND METHODOLOGY

2.1 Implementation of Schlieren Imaging Techniques

Schlieren techniques are optical methods used to visualize changes in the refractive index of transparent media. These changes typically correspond to variations in density, temperature, or pressure, making Schlieren techniques particularly useful for studying fluid dynamics, shock waves, and gas flow patterns. By detecting and capturing these variations, Schlieren imaging allows researchers to observe otherwise invisible phenomena such as airflows, gas mixing, and combustion processes.

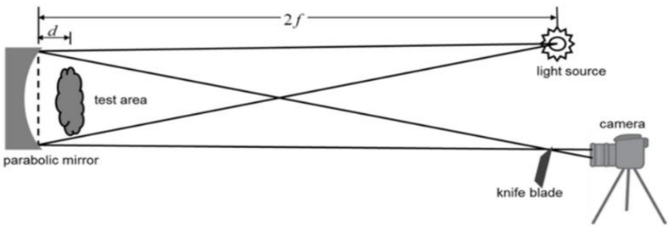

Figure 2. Simple Schlieren configuration

Schlieren techniques work by utilizing the principles of light refraction. A collimated light source, such as a laser or a point light, is directed through the transparent medium being studied. As the light passes through regions with varying refractive indices, caused by changes in density or temperature, it bends or refracts. This refracted light is then focused using lenses or mirrors onto a knife-edge or a similar optical cutoff, which blocks some of the light. The variations in light intensity that pass the cutoff are captured by a camera, creating a visual representation of the refractive index changes within the medium. This allows for the visualization of otherwise invisible flow patterns and disturbances. [4]

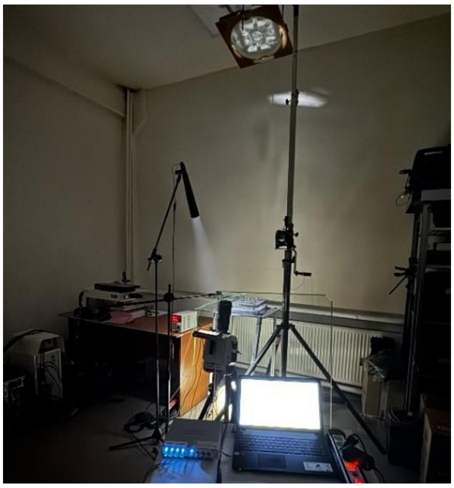

Figure 3. The Schlieren setup used for this experiment

2.2. Building of the platform for analyzing the hydrogen explosion with changing the propagation direction

In order to guarantee the optical components' alignment and stability and to allow access to the test section for the introduction of experimental setups or samples, the experimental stand's construction must be properly planned. [5] To reduce measurement disruptions, other factors like environmental management (temperature and vibration, for example) could be required.

Four interconnected chambers comprised a square spiral stand used for conducting physical tests on explosions of air-hydrogen mixtures. The building material for the experimental model used to assess the altered propagation of explosions was a polycarbonate sheet with a thickness of 20 mm.

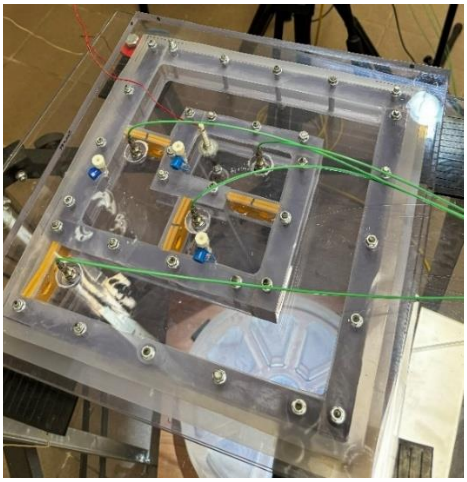

Figure 4. Experimental model for analyzing the development of air-hydrogen mixture explosions, with modification of the propagation direction

The volume of this stand was divided into 4 separate chambers, as previously described, by 4 rectangular shutters made from two plates, each with two 12 mm diameter holes, with food-grade foil inserted

between the plates. The volumes of the four chambers were, in order from the electrodes to the exit of the explosion tunnel, 150 cm³, 142.5 cm³, 207.5 cm³, and 1060 cm³. Compared to the tests carried out in the previous stage, this last volume, like the others, was sealed with a foiled shutter. The 4 pressure sensors were mounted at the shutter end of each chamber.

To simultaneously test two ignition sources within the same experiment, a hydrogen concentration configuration was used across the four chambers such that the first hydrogen-air mixture volume was initiated by an electric spark, while another explosive volume was ignited by the flame front produced by the initial explosion. [6, 7].

Thus, the first and third volumes (the first and third chambers) were set to a concentration of 30% hydrogen by volume, while the second and fourth volumes contained clean air (0% hydrogen).

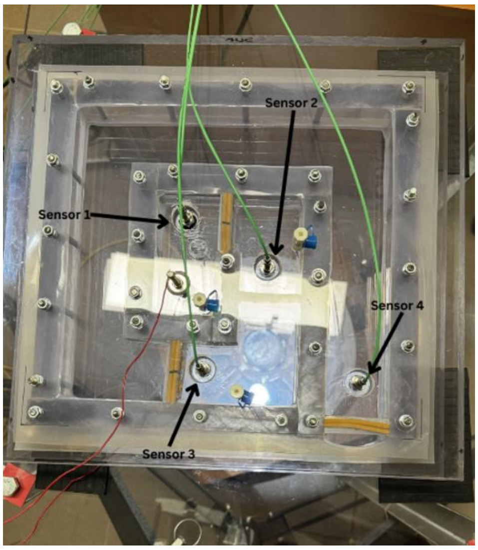

Figure 5. The polycarbonate model with its corresponding sensors

The material polycarbonate was selected because of its great stress and pressure resistance as well as transparency. The inside portion of the explosion tunnel was established at 50 x 30 mm dimensions in consideration of the safety precautions for carrying out the experiments. With this knowledge, the diameter of the parabolic reflectors used in Schlieren method recordings was the sole constraint. Consequently, a 50 mm wide by 20 mm wall spiral was built around the ignition chamber, which also contains the explosive mixture's source of initiation. This spiral continues until the end of a 412 mm-diameter circular section, which corresponds to the diameter of the parabolic mirrors depicted in Figure 6. The spiral had an internal volume of 1.56 liters with a median line that measured 1040mm in length.

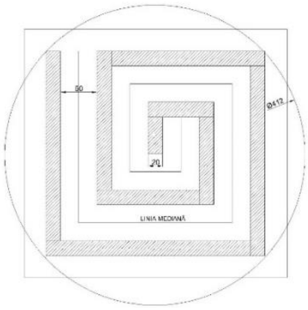

Figure 6. Sketch of the spiral model

3. RESULTS

As a result of the experiment, images of the flame front behavior were recorded, as shown in Figures below:

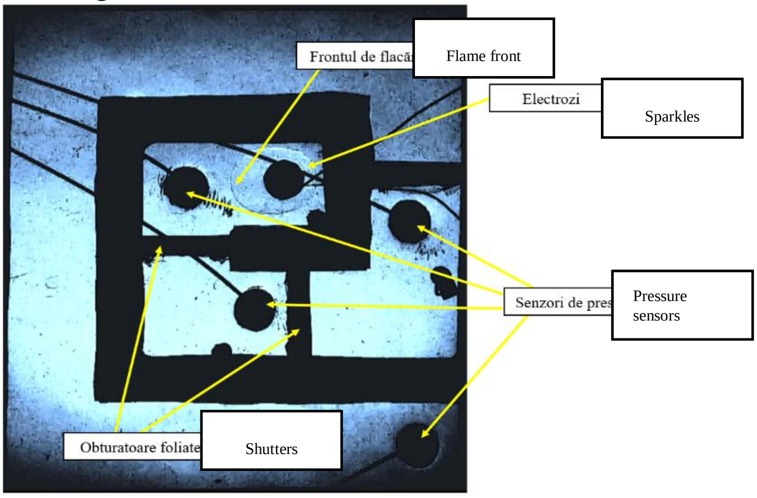

Figure 7. First initiation

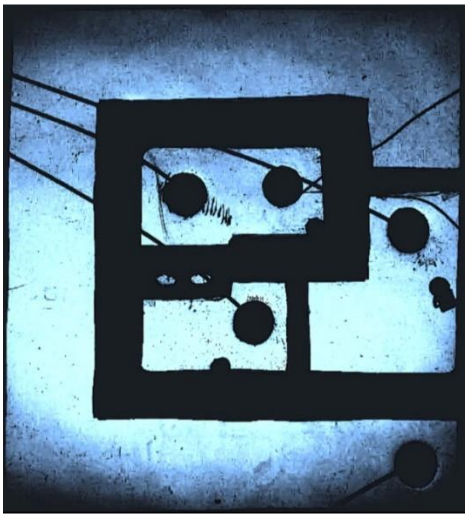

Figure 8. The rupture of the first shutter and the entry of the flame front into chamber 2

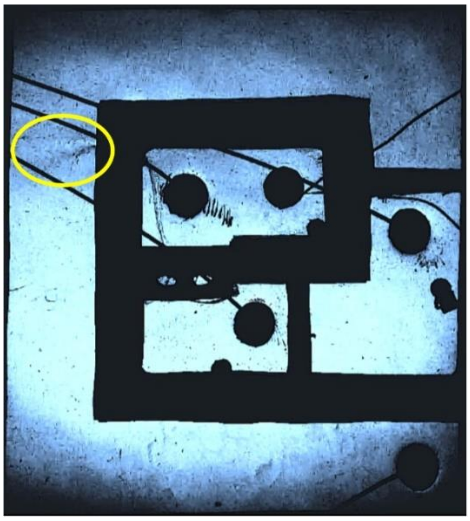

Figure 9. The occurrence of an accidental leakage of combustible gases between chambers 1 and 4

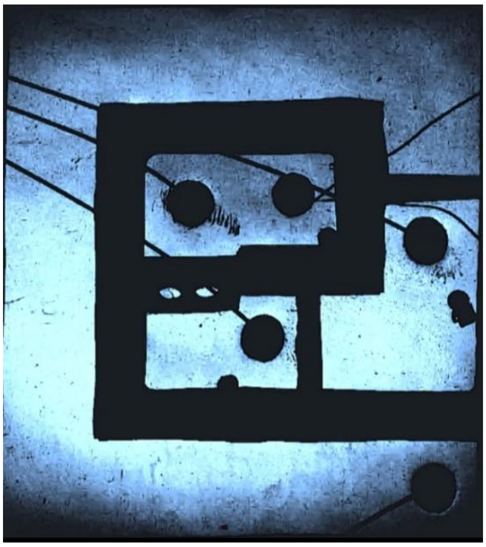

Figure 10. The almost imperceptible passage of thin flame fronts through chambers 2 and 3

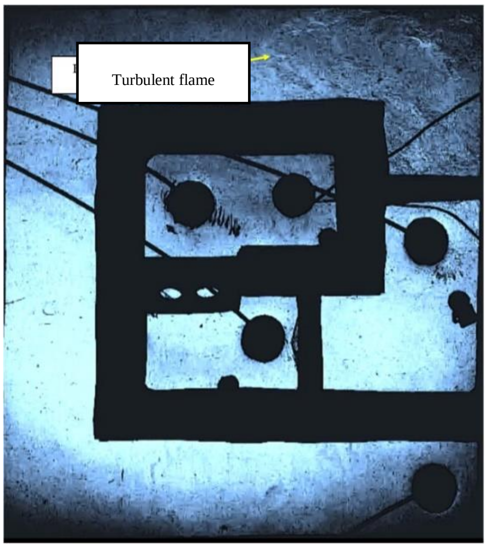

Figure 11. The occurrence of a strong turbulent flame front in chamber 4

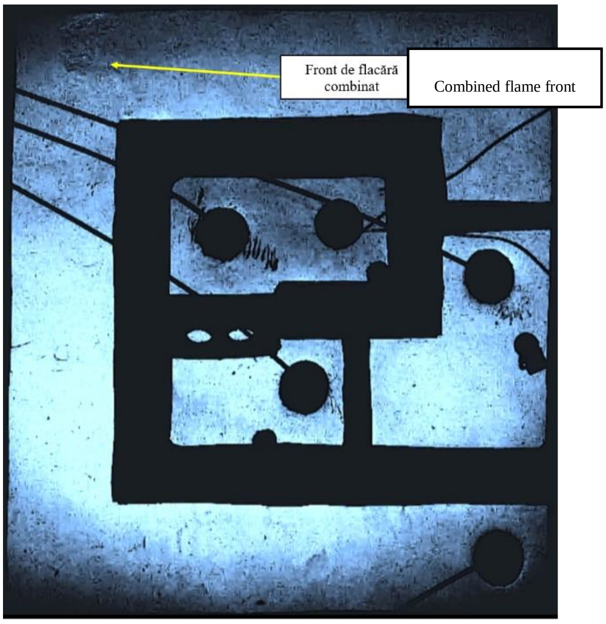

Figure 12. Ignition of combustible gas from accidental leakage and formation of a combined flame front

In this instance, the flame front's path through rooms 2 and 3 can only be seen by watching the video recordings because the front's vortices are particularly thin. However, the flame front continues past the designated chambers and into chamber 4, where it ignites the explosive environment brought about by the accidental discharge of hydrogen from the first room. Figure 13 shows the variety in explosion overpressures.

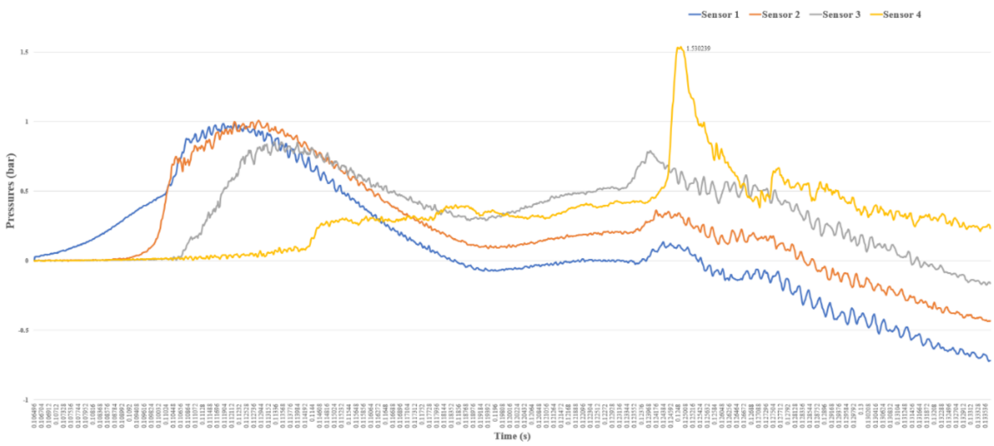

Figure 13. The variation of explosion overpressures across the 4 rooms, when changing the propagation direction

The peak values reached by each sensor are:

- Sensor 1: 0.99 bar
- Sensor 2: 1.00 bar
- Sensor 3: 0.86 bar
- Sensor 4: 1.54 bar

This work was carried out through the ”Nucleu” Program within the National Plan for Research, Development and Innovation 2022-2027, with the support of the Romanian Ministry of Research, Innovation and Digitalisation, project no. 23 32 02 02, title: Numerical modelling on the ignition and propagation of explosions generated by air-hydrogen mixtures – H2Model.

4. CONCLUSIONS

The tests have successfully validated the functionality of the experimental model in terms of its ability to accurately record explosion pressures and effectively visualize and document the behavior of the flame front. This indicates the model's reliability for simulating and studying explosion dynamics.

The experimental model, which includes a change in the direction of explosion propagation, produced pressure sensor values that significantly differ from those obtained in previous research using a linear model with similar construction specifications but without directional changes. This disparity underscores the impact of directional factors and accidental gas leakage (particularly hydrogen) on explosion dynamics.

The accidental hydrogen leakage, while posing initial safety concerns, has provided valuable insights for the research project. It has highlighted the complexities involved in the formation and initiation of explosive atmospheres during explosions, especially when occurring in different spatial configurations or with directional changes. [8]

These findings emphasize the importance of considering directional factors and unexpected gas leaks in explosion research and safety assessments. Understanding these dynamics is crucial for enhancing safety protocols, refining engineering designs, and developing more accurate predictive models to mitigate explosion risks effectively. [9, 10]

In summary, the conducted tests not only confirm the functionality of the experimental model but also reveal important nuances regarding the influence of directional changes and accidental gas leaks on explosion behaviors. These insights contribute to advancing both safety practices and scientific understanding in the field of explosion dynamics and mitigation.

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Annals of the University of Petrosani, Mining Engineering, 25 (2024)

DYNAMICS OF HYDROGEN EXPLOSION PROPAGATION IN INTERCONNECTED SPACES

Gheorghe Daniel FLOREA[1], Nicolae Ioan VLASIN[2], Vlad Mihai PĂSCULESCU[3]

Abstract: *The study of hydrogen explosions in interconnected spaces is critical for ensuring safety in industrial and laboratory settings where hydrogen is utilized. This paper focuses on a detailed physical experiment of a hydrogen explosion with linear propagation consisting of four interconnected chambers. The experimental stand was built transparent walls, allowing clear observation of the explosion process. The main purpose of the experiment was to analyze the behavior and dynamics of the explosion in a controlled environment. The main purpose of the experiment was to analyze the behavior and dynamics of the explosion in a controlled environment. For this purpose, hydrogen was introduced into the first and third chambers, while the second and fourth chambers were filled with clean air. Within NIRD INSEMEX Petroșani, an accredited institute for the elaboration of technical reports on gas explosion events, the study of the phenomenon of rapid combustion visualization has seen significant development. Physical explosion experiments have become essential and efficient tools in explaining and understanding the mechanisms of explosion occurrence. High-precision measuring instruments, such as high-speed cameras, Schlieren techniques and pressure sensors, have been used to capture and analyze data on the behavior of flame fronts. These data allow for a much better identification and understanding of the critical factors influencing explosion propagation and intensity. The results obtained from this study contribute to a deeper understanding of explosion dynamics in interconnected spaces and provide a basis for developing improved safety measures and predictive models for hydrogen explosion scenarios. Future research will focus on refining these models and exploring the influence of varying hydrogen concentrations and ignition sources on explosion propagation.*

Key words: *hydrogen explosions, interconnected spaces, physical experiments, Schlieren techniques, experimental stand.*

1. INTRODUCTION

As one of the most promising energy sources of the 21st century, hydrogen is attracting increasing attention due to its cleanliness, high calorific value, and renewable capacity. However, some unique properties of hydrogen, such as its wider flammability ranges, higher diffusivity, lower ignition energy, and faster burning speed, present

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significant risks during production, storage, distribution, and consumption. Therefore, safety issues related to hydrogen, especially explosion hazards, must be fully assessed as its widespread adoption progresses. Numerous studies have been conducted on the severity of hydrogen-air explosions. Previous studies have shown that the flame front speed and overpressure increase significantly with the addition of hydrogen, and the time to reach maximum overpressure decreases [1]. The hydrogen-air premixed flame exhibits more complex shape changes and distinct characteristics compared to other gaseous fuels. The intensity of the hydrogen-air explosion is higher than that of the methane-air explosion, and it presents greater explosion hazard effects. Many studies have also been conducted to understand the factors affecting hydrogen-air explosions, such as vent area, venting explosion pressure, number of vents, ignition position, and initial turbulence [2, 3].

These studies have provided a basic understanding of hydrogen-air explosions. In general, obstacles are present during the use of hydrogen, as with other combustible gases. The explosion flame front undergoes complex shape changes and generates unpredictable pressure waves when passing through obstacles. To date, significant research has been conducted on the effect of obstacles on the characteristics of gas explosions, including the shape of the obstacles, blockage ratio, number, location, and spacing, focusing mainly on methane, propane, LPG, and other combustible gases. However, research on the effect of obstacles on highly reactive hydrogen is still insufficient. Literature shows that the peak pressure of hydrogen flames is approximately an order of magnitude higher than that of LPG or CNG flames [4]. The degree of wrinkling and distortion of the flame front increases significantly with the number of obstacles, but the front becomes laminar as the spacing between successive obstacles increases, resulting in a decrease in pressure. For a given configuration, the structure of hydrogen flames exhibits fewer distortions and wrinkles than that of the other two hydrocarbon fuels [5, 6] at the same equivalence ratio.

This paper, entitled "Dynamics of hydrogen explosion propagation in interconnected spaces," aims to explore the complex phenomena associated with hydrogen explosions in such environments. The study seeks to investigate how hydrogen explosion waves propagate through interconnected spaces and the pressures they develop during explosion, focusing on the influences of spatial configuration and the presence of obstacles. By understanding these factors, more effective safety protocols and design principles can be developed for hydrogen storage, distribution, and utilization systems.

The research presented in this paper is based on advanced experimental data. Rigorous experiments are conducted to simulate hydrogen explosions in controlled environments, providing empirical data on hydrogen behavior under various conditions. These experimental results are essential for computational simulations of fluid dynamics, which offer detailed insights into the mechanisms of hydrogen explosion propagation.

2. EXPLOSIVE PROPERTIES OF HYDROGEN

Hydrogen, due to its physicochemical properties, presents a series of unique challenges regarding safety. For example, hydrogen has very small molecules, which gives it a high capacity to infiltrate through the smallest cracks and openings, making it prone to leaks. This property requires rigorous control of the integrity of storage and transport systems. Additionally, the minimum ignition energy of hydrogen is extremely low, meaning that even a very small spark can trigger an explosion [7, 8].

Hydrogen is recognized as a significant carrier of new energy, capable of storing and delivering energy in a usable form. At standard temperature and pressure (0°C and 1013 hPa), hydrogen exists in a gaseous state and is characterized as odorless, colorless, tasteless, and non-toxic, and it is lighter than air. The stoichiometric fraction of the mixture of air and hydrogen is 70.4% air volume and 29.6% hydrogen volume, while for the mixture of oxygen and hydrogen, the stoichiometric fraction is 66.66% air volume and 33.33% oxygen volume. Hydrogen is abundant on Earth as an element, comprising 75% of matter's mass and 90% of its volume. It is important to note that hydrogen is not a primary source of energy itself but can be produced from other energy sources such as fossil fuels, renewable sources, or nuclear energy through various energy conversion processes [9,10].

The exothermic combustion reaction with oxygen forms water (combustion heat 1.4 x 10^8 J/kg) and does not emit greenhouse gases into the atmosphere during combustion. The energy content of hydrogen is 33.3 kWh/kg (corresponding to 120 MJ/kg for the lower heating value) and 39.4 kWh/kg (corresponding to 142 MJ/kg for the higher heating value). The difference between the lower and higher heating values reflects the molar enthalpy of water vaporization, which is 44.01 kJ/mol. Higher thermal power is obtained from burning hydrogen in steam production, while lower thermal power is obtained when the produced water condenses back into liquid form [11, 12,13].

In comparison to other fuels such as methanol, gasoline, diesel, or kerosene, hydrogen provides significantly more energy per unit mass, approximately three times more than gasoline, diesel, or kerosene[25, 26]. However, hydrogen requires careful handling due to its wide flammability range. Its flammability range varies from 4% hydrogen volume (lower flammability limit) to 75% hydrogen volume (upper flammability limit) in air, and from 4% to 95% hydrogen volume in oxygen. [14, 15, 16, 17,18]. These limits are temperature-dependent, decreasing from 4% hydrogen volume at normal temperature and pressure (20°C and 1 atmosphere) to 3% hydrogen volume at 100°C [20, 27, 28].

Hydrogen has a very low minimum ignition energy, 0.017 MJ in air and 0.0012 MJ in oxygen at 25°C and 1 bar pressure. This characteristic makes hydrogen easily ignitable in the presence of an ignition source such as a spark, flame, or hot surface. During combustion, hydrogen burns with an invisible flame and emits ultraviolet light, burning extremely rapidly and causing rapid flame expansion [19, 24].

3. THE EXPERIMENTAL MODEL FOR THE ANALYSIS OF THE LINEAR DEVELOPMENT OF EXPLOSIONS OF AIR-HYDROGEN MIXTURES

Physical experiments of hydrogen explosions in a controlled environment were conducted using a specially designed and tested setup. These experiments aimed to initiate air-hydrogen atmospheres and observe the linear propagation of the explosive process. Explosion overpressures were recorded by pressure sensors placed on the stand, while high-speed camera footage obtained through Schlieren techniques allowed observation of initiation modes and flame front behavior.

3.1 Experimental setup

The structural material of the experimental model for analyzing the linear propagation of explosions was selected as 20 mm thick polycarbonate sheet, due to its transparency and superior resistance to shocks and high pressures (Figure 1).

Keeping in mind the safety of conducting experiments, the interior section of the explosion tunnel was set at dimensions of 50 x 30 mm, with the length of the stand being 1040 mm and resulted in an internal volume of 1.56 liter.

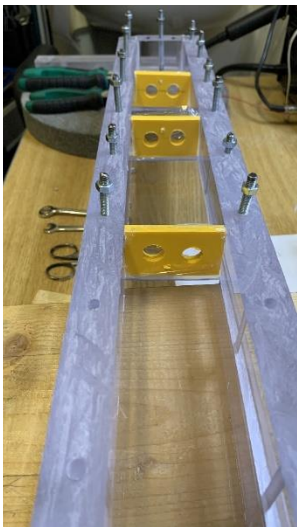


Figure 1. Progress during the construction and finalization of the linear model

For sealing, gaskets were crafted on the upper and lower closing plates of the model. Additionally, at various intervals along the median line, three rectangular shutters were constructed and mounted, each consisting of two plates with two 12 mm diameter holes [21].

Transparent plastic film was inserted between the plates to separate the tunnel into distinct chambers. The first chamber, designated for initiating the air-hydrogen mixture, was outfitted with electrodes for generating electric sparks, a cap device for introducing hydrogen, and a pressure sensor. Chambers 2 and 3 were equipped with a cap device for hydrogen introduction and a pressure sensor each, while the fourth chamber only housed a pressure sensor (Figure 2).

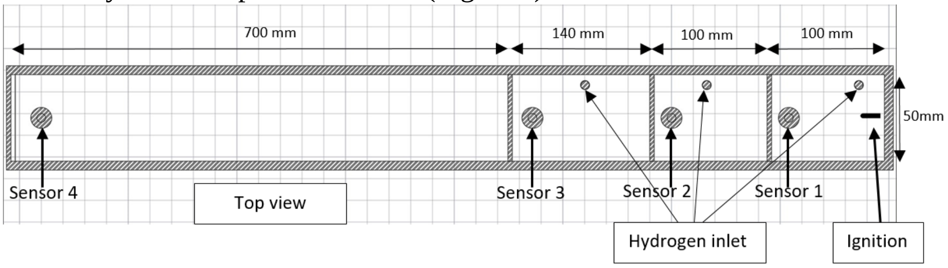


Figure 2. Schematic setup showing the ignition location, sensors positions and hydrogen inlet

The linear stand construction was positioned between two parabolic mirrors (Figure 3), with the Schlieren technique adopted. This technique involved the projection of a light beam in the shape of the letter Z, with the parallel light beam passing vertically through the interior of the construction. Eventually, it was focused by the upper mirror onto the objective of the high-speed camera for video recordings.

Figure 3. Arrangement of the construction between parabolic mirrors and the transparent frame for high speed video recordings

Schlieren techniques are optical methods used to observe refractive index gradients in gases, especially air, or in other transparent media. These gradients can be generated by differences in temperature, pressure, and density; a gas medium at high temperature has a lower density (and therefore a lower refractive index) than the same medium at normal temperature.

Figure 4 shows a type letter Z Schlieren configuration, used to visualize [29] density variations in transparent media such as air or liquids. This optical technique provides a detailed image of flow phenomena and turbulence. The type letter Z configuration is named as such due to the trajectory of the light beam, which forms a Z-shaped pattern.

In the type letter Z Schlieren configuration, light rays refracted by density variations in the medium are deviated such that the intensity of the light reaching the video camera varies. This creates a high-contrast image, highlighting areas with density variations and thus allowing for a detailed visualization of phenomena such as turbulence, air flows, or convection processes.

This technique is extremely valuable in various scientific and engineering fields, including aerodynamics, fluid mechanics, and thermal research, as it allows for the observation and analysis of the complex behavior of fluids and gases [21].

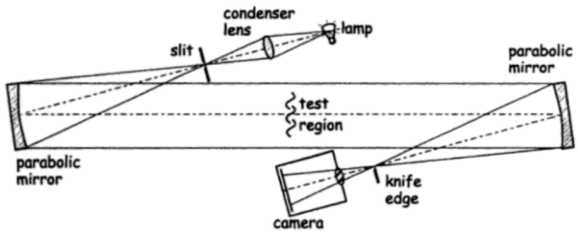


Figure 4. The layout of a type letter Z Schlieren setup

3.2 Experimental flame propagation results

The volume of this stand was divided into four rooms separated by rectangular shutters, each shutter consisting of two plates with two 12 mm diameter holes, between which plastic foil was inserted. [22, 23] The volumes of the four chambers had the following values, in order from the electrodes to the exit from the blast tunnel: 150 cm³, 142.5 cm³, 207.5 cm³, and 1060 cm³. The four pressure sensors were mounted at the shutter end of each chamber (Figure 5).

For the simultaneous testing of two ignition sources in the same experiment, a configuration of hydrogen concentrations on the 4 chambers was approached so that the first volume of air-hydrogen mixture was initiated by an electric spark, and another explosive volume was ignited by the flame front produced by the initial explosion.

Thus, the first and third volumes (first and third chambers) were set to a concentration of 30 vol% hydrogen, and the second and fourth volumes contained clean air (0% hydrogen).

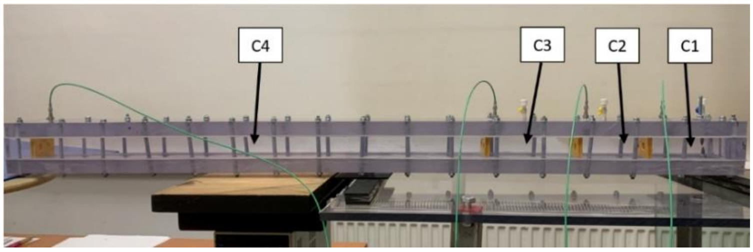
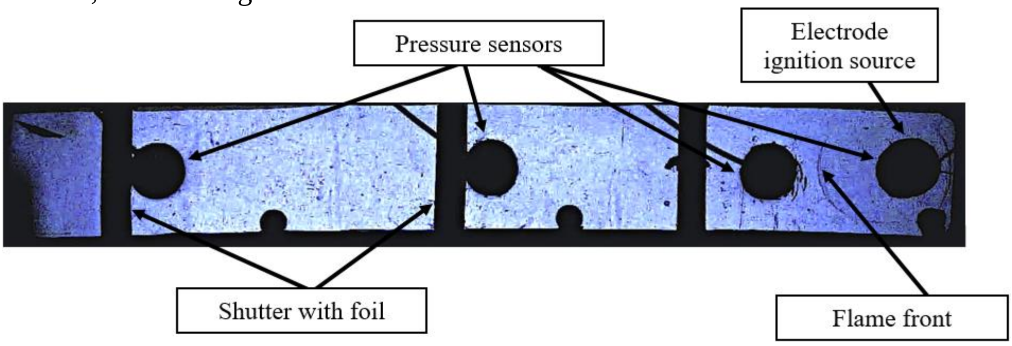


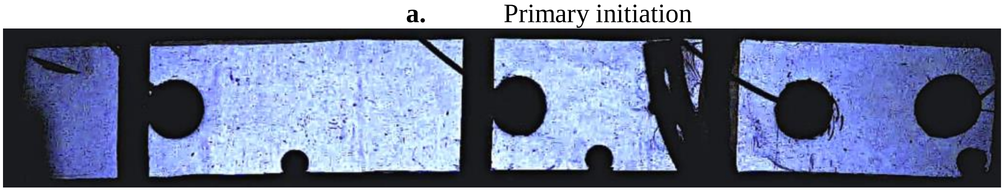
Figure 5. Experimental model for analyzing the linear propagation of explosions (C1-4 are the rooms of the stand)

Video recordings were captured using a high-speed Phantom camera operating at a frame rate of 30,000 frames per second. The high-speed camera recorded images of the flame front behavior at this rapid frame rate, allowing for detailed analysis of the dynamics and propagation of the flame.

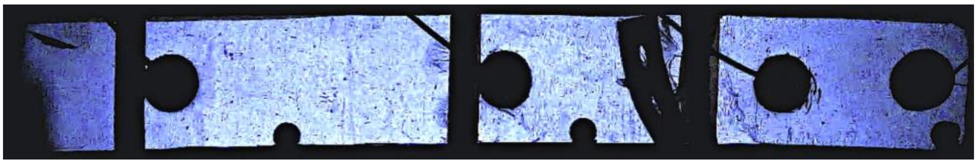
Following the experiment, images of the behavior of the flame front were recorded, shown in figure 6:



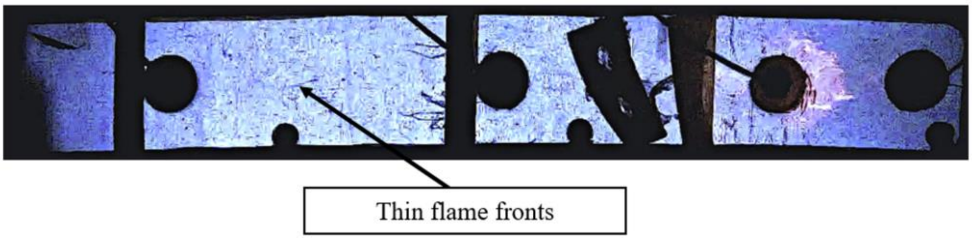
a. Primary initiation



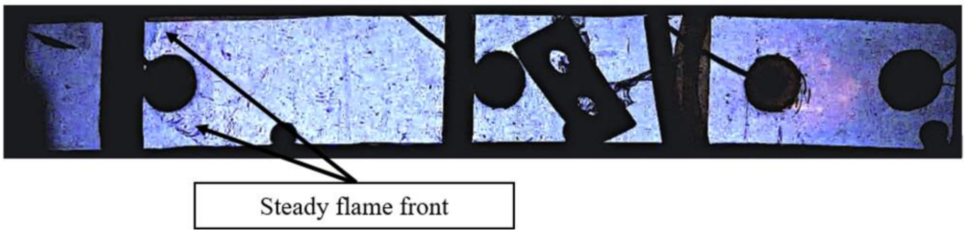
b. Breaking of the first shutter and penetration of the flame front into chamber 2



c. Breaking of the second shutter



d. Initiation of the mixture in chamber 3 and development of thin flame fronts



e. Breaking of the second shutter

f. Rupture of the third shutter and propagation of the explosion in chamber 4

Figure 6. Development of flame fronts on the linear experimental model

3.3. Pressure recordings

To record the pressure generated by the hydrogen explosion in the experimental setup, 4 Kistler piezoelectric sensors type 601CAA were selected and used. These sensors are renowned for their sensitivity to rapid pressure changes and are ideal for applications that require accurate real-time pressure measurement, such as explosion testing. The pressure sensors were connected to Kistler multichannel charge amplifier type 5165A4.

Regarding the variation of explosion overpressures, this is depicted in figure 7, with the peak values reached by each sensor as follows:

- Sensor 1: 3.83 bar;
- Sensor 2: 3.55 bar;
- Sensor 3: 5.2 bar;
- Sensor 4: 3.22 bar.
-

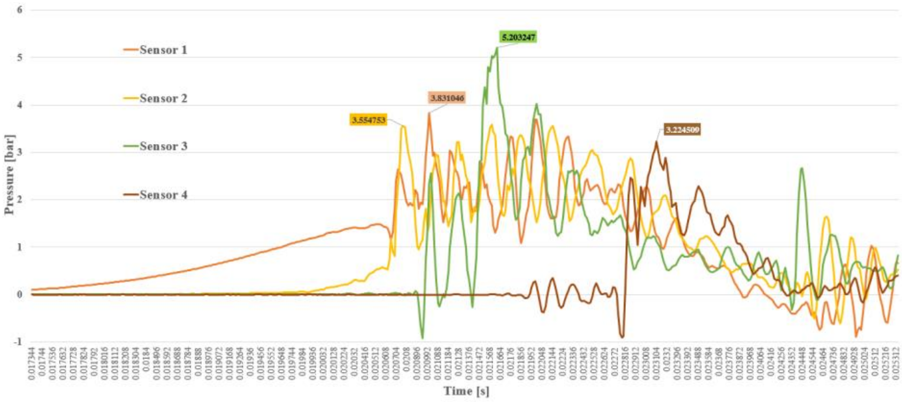


Figure 7. Variation of explosion overpressures in the 4 chambers.

It was noted that sensor 1 reached an initial pressure peak of 2.6 bar after initiation, with the maximum value on the graph reached upon the pressure wave's return. The initiation and explosion of the mixture in chamber 3 generated the highest overpressure due to the larger explosive volume and the precompression and preheating of the mixture in front of the flame front from chamber 2. Sensor 2, in the clean air chamber, reached a peak of 3.55 bar due to the combustion of combustible gases "pushed" from the first chamber, as a result of the expansion of burned gases. Sensor 4 recorded the overpressure at the experimental model outlet, where the fuel support was already consumed.

This work was carried out through the ”Nucleu” Program within the National Plan for Research, Development and Innovation 2022-2027, with the support of the Romanian Ministry of Research, Innovation and Digitalization, project no. 23 32 02 02, title: Numerical modelling on the ignition and propagation of explosions generated by air-hydrogen mixtures – H2Model.

4. CONCLUSIONS

Following the physical experiment of the air-hydrogen explosion, it was observed that the selection of construction materials and the assembly method of the elements were appropriate decisions, as the experiments proceeded safely. No cracks, fractures, or displacements were detected in the structural integrity of the model [13]. This demonstrates that the materials and methods used successfully withstood the forces generated by the explosion. The movements of the shutters, observed during the experiment, are anticipated dynamic effects typically generated by explosion overpressures. Thus, the conducted experiment demonstrates the functionality of the experimental model, both in terms of recording explosion pressures and visualizing and recording the behavior of the flame front, as well as ensuring safety in operation [18].

The experimental setup and the use of Schlieren techniques represent valuable tools for researching and understanding hydrogen explosions. Not only do they help us observe and record the behavior of the flame front in real time, but they also allow us to evaluate and improve theoretical models, which significantly impacts the development of more effective safety strategies in various industrial and scientific fields.

Experimental setup, divided into four chambers separated by rectangular shutters, allowed for a detailed evaluation of explosion propagation in a controlled environment. The simultaneous use of two ignition sources successfully demonstrated how the flame front generated by the first explosion can ignite another explosive volume, confirming the anticipated theoretical behavior.

The data obtained from the pressure sensors mounted at the end of the shutters provided detailed information on the evolution of pressure during the experiment, thus validating the experimental approach and providing a solid foundation for improving theoretical models and security strategies in handling hydrogen in various industrial and scientific applications. These results have the potential to contribute to the development of more precise and efficient safety standards and regulations for the use of hydrogen in diverse technological contexts.

The results obtained from this study contribute to a deeper understanding of the dynamics of explosions in interconnected spaces and provide a basis for developing improved safety measures and predictive models for hydrogen explosion scenarios. Future research will focus on refining these models and exploring the influence of varying hydrogen concentrations and ignition sources on explosion propagation.

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CHECKING THE SECURITY OF EXPLOSIVES FOR CIVIL USE UNDER CONDITIONS OF HIGH TEMPERATURES

Cristian Raul CIOARA[1], Marius Simion MORAR[2], Andrada Denisa MATEI[3], Ștefan ILICI[4]

Abstract: *Explosives for civil uses are part of the category of dangerous products, representing a significant risk of explosion during storage and handling under conditions of exposure to high temperatures. The main risks associated with the use of explosives for civil uses are those of uncontrolled explosion, fire or poisoning by combustion products. The importance of the field is argued by the fact that for the civil explosives, the European Union promoted the Directive for explosives (2014/28/UE), which regulates the marketing of these products. This paper refers to the verification of the thermal stability of explosives for civil uses, in order to evaluate the fulfillment of the essential security requirement of Annex 1 of the Directive (2014/28/UE), "Physical and chemical stability of the explosive in all environmental conditions that can be exposed", taking into account the major risk of an uncontrolled explosion as a result of improper storage conditions and/or a major damage situation (fires).*

Key words: *explosives, chemical stability, high temperatures, essential security requirements.*

1. INTRODUCTION

Explosives for civil use are part of the category of dangerous products, representing a significant risk of explosion during storage and handling under conditions of exposure to high temperatures.

The main risks related to the use of explosives for civil use are those of uncontrolled explosion, fire or poisoning with combustion products. The importance of the field is argued by the fact that for civil explosives, the European Union promoted the Explosives Directive (2014/28/EU), which regulates the marketing of these products. [3,5]

In the mentioned Directive there is a technical requirement related to the security of explosives that must be evaluated before placing on the market, by testing the products according to harmonized standards aimed at ascertaining compliance / non-compliance with the relevant security requirements.

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The thermal conditioning and temperature resistance verification for civil explosives is an operation lasting from several hours to several days and with significant risks for the personnel in charge of performing these tests, reproducing the extreme conditions of exposure to heat flow in reality. [2,3]

The test is carried out with the aim of evaluating the fulfillment of the essential security requirement from Annex 1 of the Directive (2014/28/EU), "Physical and chemical stability of the explosive under all conditions in the environment to which it may be exposed", and reproduces the situation in practice where due to improper storage conditions or due to major damage situations (fires), the explosive is subjected to a considerable thermal flow in a short period of time, with a major risk of producing an uncontrolled explosion. [5]

In a wider context this test, described by SR EN 13631-2 "Explosives for civil use, high explosives. Part 2: Determination of the thermal stability of explosives", verifies compliance / non-compliance with the essential security requirements specified in point: I.1; II.1(b) and II.1(d) of the directive: [5]

- Any explosive must be designed, manufactured and supplied in such a way as to present a minimal risk to human life and health, the integrity of property and the environment, under normal and foreseeable conditions, in particular with regard to safety rules and standard practices, including those relating to the period before use;
- The physical and chemical stability of the explosive in all conditions in the environment to which it can be exposed;
- The compatibility of all components in terms of their physical and chemical stability.

The equipment described by the mentioned European standard is specially made for this test and allows a high level of confidence determination of this characteristic.

At the moment, this standardized test with the name "Determination of the thermal stability of explosives" is not carried out according to the CEN standard, as the infrastructure provided for by SR EN 13631-2 is not available, but at the moment, it is carried out in the accredited laboratory of the INCD INSEMEX Petroşani- an Abel chemical stability test that allows, as an alternative method, the evaluation of the previously stated essential safety requirements. [6,7]

Most European countries, with specialized laboratories, have switched from the "classic" Abel test to the test provided by SR EN 13631-2, considering that its confidence level is clearly higher than the previous one.

2. PROCEDURAL ASPECTS REGARDING THE PERFORMANCE OF THE CHEMICAL STABILITY TEST WITH THE ABEL EQUIPMENT

The Abel test, used to verify the behavior of explosives when exposed to heat flow, has been used in recent decades, being promoted at the national level by the Romanian standard STAS 418-85 "Mining explosives. Dynamite type II", the principle of the Abel method consisting in heating the explosive substance to temperatures of +75°C and following its behavior over time. Thus, the explosive is considered chemically stable, if the indicator paper is not colored, due to nitrate vapors, possibly resulting from the decomposition of the substance being tested (STAS 418-85 Mining explosives. Dynamite type II). [6,7]

To perform the chemical stability test with the Abel equipment, the following are required:

- **test tubes** made of chemically neutral, colorless glass, 140-150 mm long, 14-16 mm inner diameter and 1-1.5 mm wall thickness, provided with three markings, rubber stoppers provided at the bottom with platinum hooks, lids made of non-transparent material (cardboard), technical balance with weighing accuracy of at least 0.01 g, timer with accuracy of 0.1 s, mortar with wooden or glass pestle, glass funnel, capillary tube tapered at one end, tweezers, solution of glycerin in water, 1:1 vol., iodine-starched indicator paper, specially prepared talc, glass rod.
- **Oven,** capable of controlling the temperature at 75 ± 2°C (Figure 1).

Figure 1. Oven

The oven must have double thermostats or other means of protection against possible overheating in case the control thermostat fails, preferably, the oven must be isolated and capable of remote operation. It must also be equipped with a ventilation system and the electrical equipment must be safe for use with explosives.

- **Three thermocouples,** of the appropriate type, inert to the tested substance. If the coating is not inert to the tested substance, an inert jacket with a thermal resistance as low as possible is used.
- **Temperature recording system,** capable of measuring the temperature with an accuracy of ± 1°C (Figure 2).

Figure 2. Temperature recording system

- **Two glass tubes** (Figure 3) with a flat bottom, with an inner diameter of (50.5 □ 0.5) mm, with a length of approximately 150 mm and a thickness of approximately 3 mm. For closure, the tube with the substance under test must be equipped with a gas-tight device with a low resistance consisting of a rupture disk calibrated at a standard static pressure of 60 kPa or with a continuous pressure measuring device. The equipment must be provided with a valved means to the explosive heating device. [6,7]

Figure 3. Glass tubes

3. PREPARATION OF SAMPLES

- For liquid substances in paste or granular form:
  The test sample must have a volume of (100 ± 4 ml). Particles larger than 4 mm must be crushed before testing. [6,7]
- For compact solids
  The sample must be tested in cylindrical blocks with a diameter of 49 mm and a length of 50 ± 1 mm.

4. WORKING METHOD

If no information is available on the thermal behavior of the substance, the test should be carried out using a small amount of the substance, for example 5g, to determine whether the substance explodes at 75 °C.

Adjust the oven temperature to 75° C ± 2° C.

After weighing an empty glass tube, insert the test sample into the tube.

If the substance is a liquid, a paste or granular solid is poured or placed inside the tube.

Granular solids are tested without being compacted. The substance should fill the bottom of the tube to a height of 50 ± 1 mm, resulting in a sample volume of 100 ± 2 ml.

In the case of compact solids, the test sample consists of a cylindrical block. Place the block on the bottom of the tube.

Weigh the tube with the substance to be tested to determine the mass of the test sample and obtain the charge density of the substance using the formula:

$$\rho = M / V \tag{1}$$

Pass the thermocouple wires through the closure so that the tip of the thermocouple is 2 mm from the center of the sample. In the case of a compact solid, it shall be placed in the impervious hole of the test specimen block.

Place (100 ± 2) ml of the reference substance in the other glass tube, by the same procedure as described above, but without weighing. Insert thermocouple 2 and close the tube.

The two tubes are placed 10 cm apart inside the test tube. The thermocouples are connected to a temperature recording system with the switch on.

The temperatures of the test substance and those of the reference substance are recorded by thermocouples 1 and 2. The temperature inside the oven is recorded by the third thermometer.

After the test sample and the reference substance have reached a temperature of (75 ± 2) °C, release the pressure and continue the test for 48 (+1) h unless one of the following occurs:

a) crackle or flame;

b) release of gas and rupture of the filling disc;

c) self-heating of the substance under test;

If one of the above phenomena occurs, the trial will be terminated. The oven is closed and after it has cooled, the contents are examined. If the test is completed after 48 (+1) hours, the oven is closed and after it has cooled, the test tube is taken and weighed to determine if loss of mass has occurred.

If none of the phenomena: a, b or c was observed, the final result is recorded as: "no reaction", otherwise the result is recorded as "with reaction".

5. RESULTS

INCD INSEMEX Petroșani, through the SECEMTI certification service, participated in the interlaboratory testing scheme (generically called Round Robin Test - RRT), organized by TÜV Rheinland InterCert Kft., Hungary, which aims to test explosives in accordance with the described method in the SR EN 13631 - 2 standard "Determination of the thermal stability of explosives".

The object subjected to the tests: The gray solid sample (Figure 4), being formed by the homogeneous mixture of five substances (Figure 5), having a mass of 6.75 g., the samples were taken by TÜV Rheinland InterCert Kft., Hungary and sent to INCD INSEMEX Petroșani.

Figure 4. Sample before testing

Figure 5. Image of sample components (1, 2, 3, 4, 5) and 6 reference material

Figure 6. Image of the sample during the test

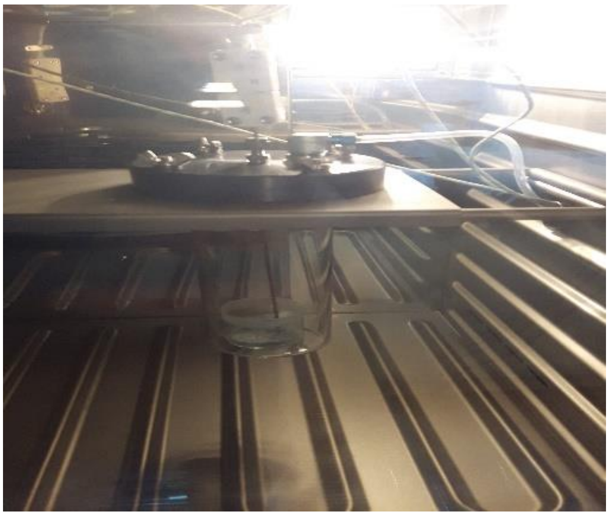

Figure 7. Image of the sample after the test

Results of the sample subjected to the tests:

- No reaction, thermally stable at temperatures of 75 °C for 48 hours;
- Mass loss is 0.077 g;
- The charge density is: 1.12 g/ml.

6. CONCLUSIONS

- Thermal stability tests are generally tests to determine/verify product shelf life. Stability tests are expected not to damage the physico-chemical structure of the product and to be suitable for use.

- Stability tests by increasing the temperature are also called accelerated aging tests.

- Accelerated test during the test period by exposure to aging at temperatures higher than the normal shelf life is shortened, and the temperature would result in a shorter time taken in this regard.

- It is extremely important that products are stable in addition to their functional uses. Stability tests allow us to learn about the physical and chemical quality of the product, as well as their stability during storage, transportation and end-user consumption.

- The interlaboratory tests (Round Robin Test – RRT) aim to ensure a constant and high quality of the results and to provide reliable proof of competence to both clients and authorities.

- The procedural determination of the thermal stability of explosives, according to SR EN 13631-2, under valid conditions for obtaining reliable results, provides the premises for increasing the technical quality of testing explosive explosives, in parallel with improving the degree of confidence in the performance evaluation of these dangerous products, as a result of the full satisfaction of the safety requirements provided by the Directive (2014/28/EU).

7. ACKNOWLEDGEMENTS

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POST-EDITING OF THE IMAGES OBTAINED FROM THE PHYSICAL EXPERIMENTS OF HYDROGEN EXPLOSIONS

Laurentiu MUNTEANU[1], Marius Cornel SUVAR[2], Zoltan VASS[3], Adina Cristina PASCULESCU[4]

Abstract: *Hydrogen is recognized as an ecological fuel due to the fact that it does not emit greenhouse gases when used. However, the explosion risk associated with hydrogen is a significant hazard in production, storage, transport and use activities, requiring rigorous safety measures. This paper presents the experimental results of explosions of a mixture of air and hydrogen carried out on two specialized laboratory stands with different geometries. The Schlieren technique was used for imaging the shock wave and flame front propagation phenomena. Due to the weak highlighting of the flame front in the raw images obtained, it was necessary to post-process them using specialized software for video editing in order to improve the clarity and visibility of the relevant details. The results obtained from the presented study provide a deeper understanding of the behavior of the flame front in explosion conditions on stands of different geometries, contributing to the improvement of safety and efficiency in industrial and research applications.*

Key words: *Hydrogen hazard, explosion, laboratory stand, Schlieren technique*

1. INTRODUCTION

In the context of current concerns about climate change and the need to reduce greenhouse gas emissions, hydrogen has become a topic of particular interest due to its potential as a clean energy source. The use of hydrogen in various industrial and transportation applications relies on its environmental advantages, but it also brings with it significant safety challenges. Among them, the risk of explosion is a major problem that requires strict and well-founded measures to prevent dangerous incidents.

This paper focuses on an aspect regarding the post-processing of images obtained from physical experiments of hydrogen explosions. The experiments were carried out on two types of laboratory stands with different geometries: one with a linear configuration (Figure 1) and the other with a prototype designed in the form of a rectangular spiral (Figure 2), equipped with metallic walls to ensure the necessary resistance to horizontal overpressures.

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The Schlieren technique was used to capture and study the dynamic phenomena of hydrogen explosions. This optical method allows the visualization of density changes in the air, characteristic of shock waves and flames [1]. However, the raw images obtained from the high-speed camera (one of the fastest industry video cameras with thousands of frames per second) used in the experiments did not provide sufficient clarity of the flame front, making their post-processing necessary.

The main objective of this work is to improve the visibility and clarity of experimental images through advanced video editing techniques, using professional video editing software (Adobe After Effects). This post-processing aims to highlight the relevant details of the flame front and shock wave propagation, thus facilitating a more in-depth and precise analysis of their behavior under different experimental conditions.

The results obtained from this endeavor are essential to develop safer and more efficient solutions in the field of hydrogen production, storage, transport, and use, with significant implications for industrial applications and future research.

1.1. Hydrogen Explosions

Hydrogen is an attractive fuel due to its high energy density and the absence of carbon emissions during combustion. However, its physical and chemical properties create significant safety risks. Hydrogen is highly flammable and can form explosive mixtures with air at relatively low concentrations. Hydrogen explosions can be triggered by very small ignition sources, and the resulting shock waves and flames can cause property damage and severe human injury [2].

Explosive Properties of Hydrogen are characterized by [3]:

Flammability Range: Hydrogen has a very wide flammability range, from about 4% to 75% volume in air.

Ignition Energy: The minimum energy required to ignite a hydrogen-air mixture is very low, around 0.02 mJ, compared to other flammable gases.

Propagation Speed: Hydrogen has a very high flame propagation speed, which means hydrogen explosions can spread quickly and generate powerful shock waves.

Diffusibility: Hydrogen diffuses rapidly in air due to its low molecular weight, which facilitates the formation of homogeneous mixtures with air.

1.2. Experimental Stands for Monitoring Hydrogen-Air Explosions

To understand and evaluate the risks associated with hydrogen explosions, we used experimental stands specially designed for monitoring and analyzing these phenomena. These stands enable the recreation of explosion conditions in controlled environments, ensuring the collection of data essential to the development of effective safety measures.

1.2.1 Types of Experimental Stands

1.2.1.1 Linear Stand (Figure 1)

A stand with a linear configuration allows the study of shockwave and flame propagation in a fixed direction. This is often used to analyze shockwave and flame behavior in simple and well-controlled environments *[4]*.

Its advantage consists of a simple geometry that facilitates accurate measurements and theoretical models.

1.2.1.2 Rectangular Spiral Stand (Figure 2)

This type of stand is designed in the form of a rectangular spiral, with metallic walls to withstand horizontal overpressures. It is used to study the effects of shockwave and flame propagation in more complex media *[3][5]*.

Its advantage is represented by its complex geometry that allows observation of how shock waves and flames interact with obstacles and changes in direction.

1.2.2 Technical Characteristics of the Stands

The relevant technical characteristics for the studied stands are the construction materials, sensors, and measuring equipment, the applied Schlieren technique.

Metallic walls are essential to withstand overpressures generated by explosions and to protect measuring equipment.

The stands are equipped with pressure sensors, high-speed cameras, and data capture equipment to monitor and record details of the propagation of the shock wave and flame front.

To visualize density variations in air, the Schlieren technique is used, which is crucial for studying flame and shock wave dynamics.

1.2.3 Post-Processing Techniques

Images obtained from experiments are often post-processed to improve clarity and detail visibility. Adobe After Effects is an advanced video editing software used to optimize images and highlight the flame front and shock waves.

When improving sharpness, post-processing techniques include adjusting contrast, applying specific filters, and correcting colors to make details more visible.

Post-processing allows a more detailed analysis of the behavior of the shock waves and the flame front, facilitating the understanding of explosion mechanisms and the development of safety measures.

2. SETTING STANDS WITH SCHLIEREN TECHNIQUES

To investigate the dynamic phenomena of hydrogen explosions in detail, it is essential to use advanced visualization techniques that can rapidly and accurately capture these events. One of the most effective techniques used for this purpose is the Schlieren technique. This chapter describes the setup of experimental stands using the Schlieren technique to monitor and analyze hydrogen explosions.

2.1 Principle of the Schlieren Technique

Schlieren technique is an optical method that allows the visualization of density variations in a transparent medium. These density variations are characteristic of the shock waves and flames that propagate during a hydrogen explosion. The basic principle of the Schlieren technique is based on the deflection of light as it passes through regions of varying density.

The two stands mentioned above are made of 20 mm thick polycarbonate sheet due to its transparency properties and superior resistance to shocks and high pressures [6].

Figure 1. Experimental model for the analysis of linear explosion propagation caused by air-hydrogen mixtures

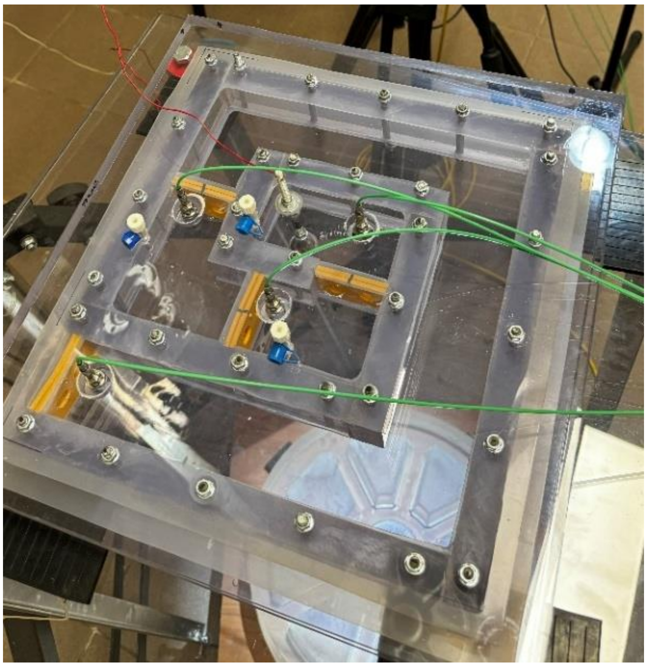

Figure 2. Experimental model for the analysis of the development of explosions of air-hydrogen mixtures, with the change in the direction of propagation

3. UNPROCESSED AND PROCESSED IMAGES

In both cases (the linear and the spiral model) concentrations of 20% vol hydrogen in air were used to charge the three chambers separated by the shutters with foiled holes previously described. The first (initial) chamber of each model was equipped with a pressure sensor, with computer-assisted recording of values. The volumes of the chambers were 157.5 ml (chamber 1), 138 ml (chamber 2), and 193.5 ml (chamber 3), the rest of the blast path being left open, in fresh air.

The video recordings were made with the help of a Phantom high-speed camera, at a frequency of 30,000 fps.

3.1 Analysis of Schlieren Images

In the case of the linear model, the process was relatively similar to the spiral model, with the difference that the first shutter was more dynamically affected than in the spiral model. During this experiment, the flame front traveled through all three chambers breaking the shutter foils and extinguishing when the fuel gas ran out (Figure 3-6).

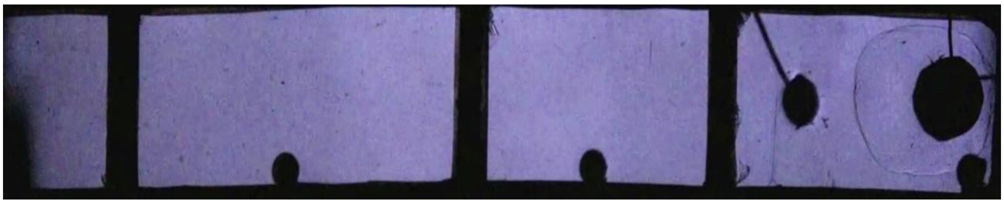

Figure 3. The first stage of the air-hydrogen explosion – raw images

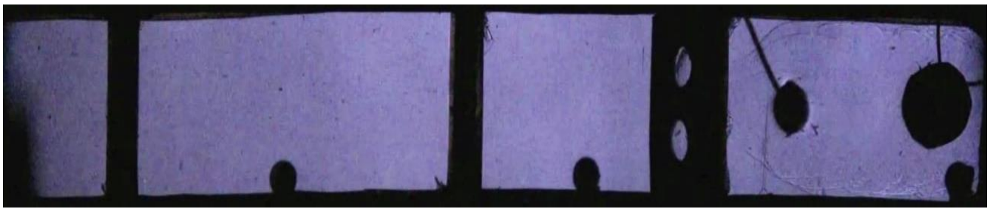

Figure 4. The 2nd stage of the air-hydrogen explosion – raw images

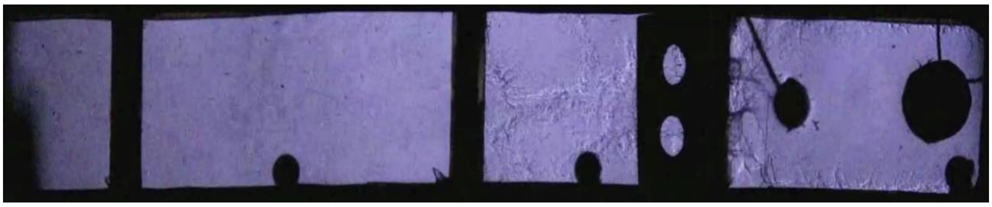

Figure 5. The penultimate stage of the air-hydrogen explosion – raw images

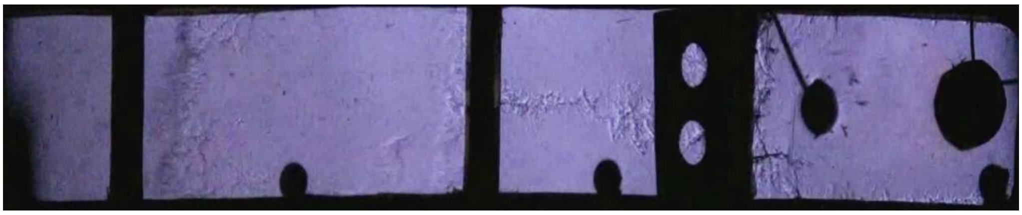

Figure 6. The last aspect of the development of the explosion at the level of the experimental model for the analysis of the linear propagation of explosions caused by air-hydrogen mixtures

The results, in the case of the spiral model, highlighted the initiation and development of the explosion of the air-hydrogen mixture and the propagation of the flame front through the three chambers (by breaking the foils of the shutters), the passage of the flame front into the space behind the shutters and its extinguishment with the consumption of the fuel support (Figure 7-10) [3][5].

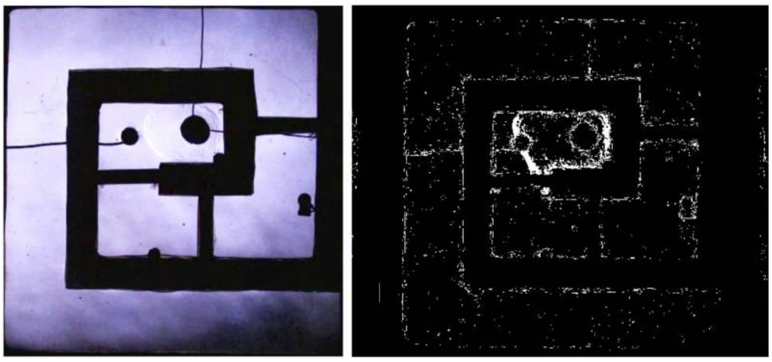

Figure 7. The first stage of the air-hydrogen explosion, with the change in the direction of propagation - images before and after video processing

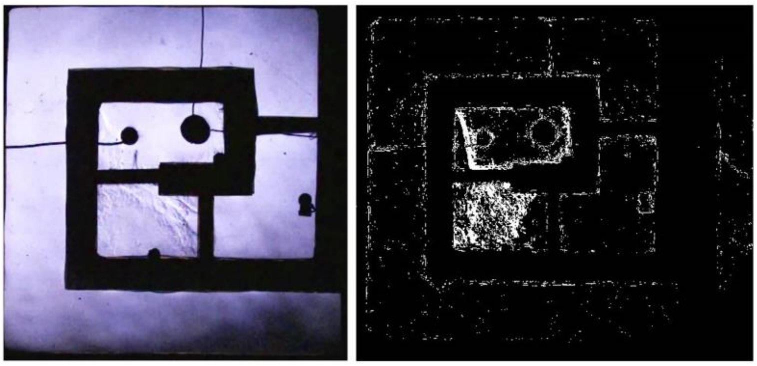

Figure 8. The 2nd stage of the air-hydrogen explosion, with the change in the direction of propagation - images before and after the video processing

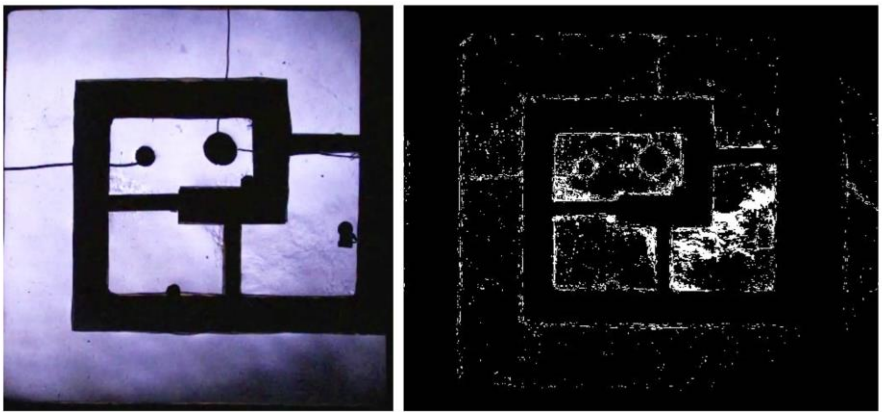

Figure 9. The 3rd stage of the air-hydrogen explosion, with the change in the direction of propagation - images before and after the video processing

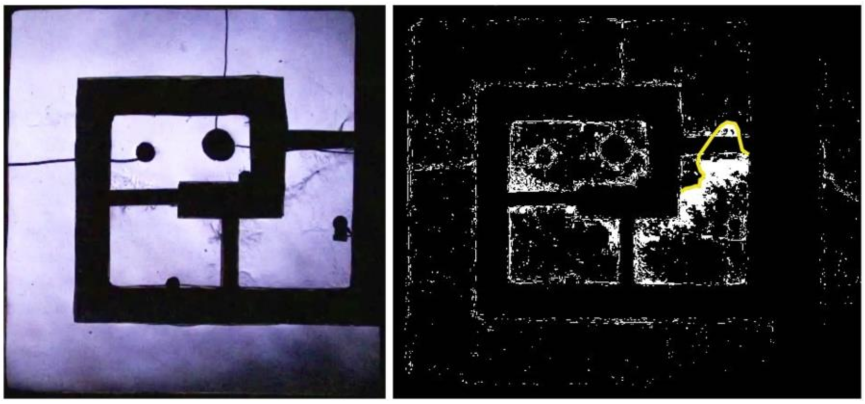

Figure 10. The last aspect of the images before and after the graphic processing, edited with the layer Shape

After setting up and performing the experiments, the images obtained with the Schlieren technique are subjected to basic processing using the proprietary software of the high-performance, high-speed camera, named Phantom Camera Control (PCC). The application allows fine-tuning of the resolution, frame rate, exposure, memory segmentation, trigger modes, and different automation before the video recording. PCC includes the ability to perform some basic measurement functions from motion analysis and also includes a histogram to judge exposure, and controls to adjust basic and advanced image parameters. The resulting files are saved as Cine files, raw-type files that include all the applied parameters as metadata and are only integrated when converted to other different video formats. Cine files can be viewed immediately and then automatically saved to a spreadsheet for review. PCC software can convert those Cine files to a variety of standard video and image formats, as required. It is therefore worth noting that the PCC application does not offer sufficient facilities for post-processing the resulting images, which leads to the need to import them into other professional applications, specialized in this sense.

3.2 Professional Post-Processing with Adobe After Effects

Using Adobe After Effects allows the application of advanced video editing techniques to highlight the essential details of Schlieren images. So:

- By applying Color, Brightness, and Contrast Effects one can adjust the color parameters to get a better visibility of the density variations and change the brightness and contrast to emphasize the subtle differences and make the flame fronts and shock waves more visible.
- By applying the Difference Mate effect, the frames from the video sequence can be compared with the first image of the clip, respectively the differences between the frames are highlighted, allowing the identification of movements and dynamic variations of shock waves and flames (Figure 11).

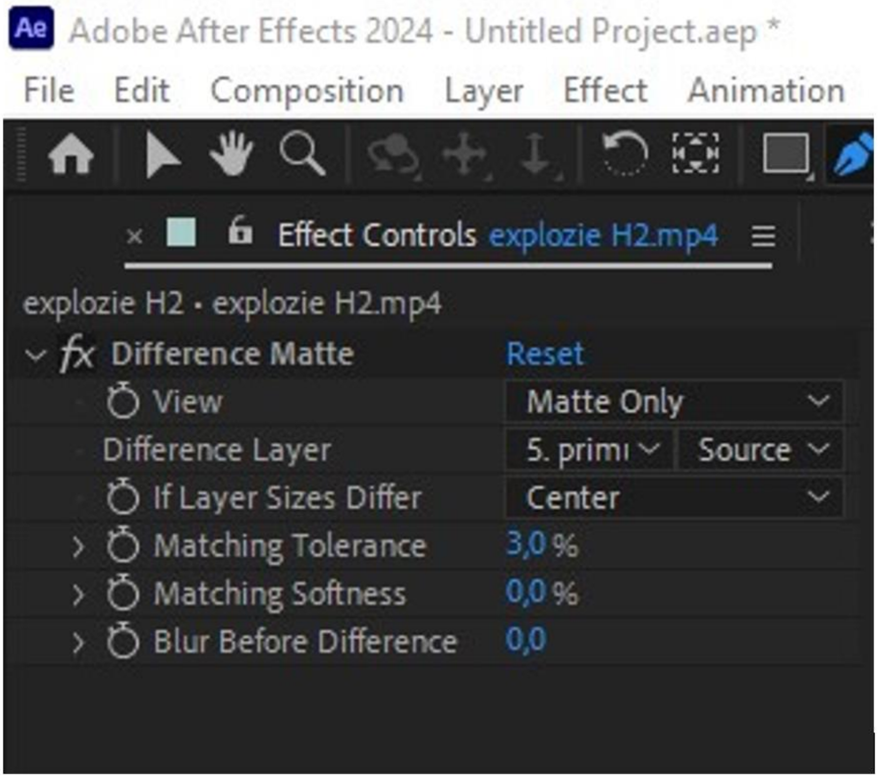

Figure 11. Setting the Difference Mate effect in Adobe After Effects

The method described in this paper for highlighting the movement of the flame front is similar to the BOS (Background Oriented Schlieren), a similar method that allows visualization of density changes using a structured background and monitoring its distortions.

3.3 Performance Evaluation of Experimental Stands

Following the physical experiments of the air-hydrogen explosions on the two models - linear and spiral - it was found that the choice of construction materials and the method of assembling the elements was adequate, ensuring the conduct of the experiments in perfect safety. No cracks, fractures, or displacements were detected in the resistance structure of the models. Shutter displacements are expected dynamic effects normally generated by blast overpressures.

These experiments demonstrate the functionality of the two experimental models, both from the point of view of recording the explosion pressures, as well as visualizing and recording the behavior of the flame front, as well as operational safety.

4. CONCLUSIONS

Setting up experimental stands with the Schlieren technique and using advanced post-processing techniques in Adobe After Effects are essential for obtaining high-quality images of the dynamic phenomena associated with hydrogen explosions. By applying specific software effects, the first frame of the video material is compared with each subsequent frame, highlighting the differences between this first frame and the current frame. Thus, pixels that have undergone color changes become much more visible, facilitating the analysis.

In some situations, the flame front may be difficult to see except when the footage is played back in motion. In these cases, it is recommended to use Shape layers, which allow the user to "draw" the shape of the flame front on the image, ensuring a clearer highlight. This is particularly useful in cases where raw images are inconclusive. For scientific materials, such as published articles and books, where it is not possible to view a moving action, it is recommended to use a suite of images illustrating the behavior of the flame front in its dynamics.

Through these methods, researchers can gain a detailed and precise understanding of the behavior of shock waves and flames. This significantly contributes to the development of more effective safety measures for the use of hydrogen as a clean energy source. In conclusion, the integration of Schlieren techniques with advanced post-processing provides powerful tools for improving the quality and clarity of experimental data, thus ensuring progress in safe hydrogen research and application.

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CONSIDERATIONS OVER THE PRODUCTION, TRANSPORT AND STORAGE OF THE HYDROGEN USING THE NATURAL GAS PIPE SYSTEM, IN A MAXIMUM MIX OF 25%V/V

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Abstract: *Mixing the natural gas with hydrogen has become a problem of national interest in Romania, for the introduction of hydrogen into the circuit: production from renewable sources, storage and transport, using the natural gas pipes, including the possibilities of hydrogen extraction from the mix, for various other purposes. Various analyses, through Lazard studies, show that a 25% v/v (by volume) mix of hydrogen with natural gas is feasible for use in power picking plants, when the energy demand is high, and the price of hydrogen (production/ transport/ storage/ mixing/ etc.) thus entering into the sale price of the produced energy [1, 2]. Other analyzes by the so-called "Hydrogen Valley" platforms, show a major interest in the development of partnerships from various areas of research and development sectors and private companies, for development of technologies in the field of production/ storage/ transport/ mixing/ etc. of hydrogen with natural gas, in proportions of 25%, as a first step for the gradual decarbonization around the globe. The paper presents, also, a diagram of connections between different research and development sectors and private companies, in order to appreciate the technological level involved in finding feasible solutions, according to the National Hydrogen Strategy [3].*

Key words: *mixing natural gas with hydrogen, hydrogen national strategy, global decarbonization*

1. INTRODUCTION

In the near future, the maximum mixing of hydrogen with natural gas for its transportation, is expected to remain limited to around 25%v/v as a B level for the hydrogen readiness implementation in the natural gas grid [4]. Europe will implement also, a number of “Hydrogen Valleys” with a backbone grid connecting those valleys and large-scale generation facilities [5]. The aim for so called “Hydrogen Valleys” is to

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have a geographically defined scope, to cover the whole range of hydrogen value chain phases: production, transformation, transportation and end use, and to be not limited to a single sector of use, but for different end users, with invesments beyond demonstration projects [6].

The origin of Hydrogen Regions (Fuel Cell and Hydrogen Regions – FCH-R) began with the year 2002, when have been made the first Joint Ventures or Joint Undertakings (JU) when an independent, tripartite High Level Group (HLG) did offers a method for structured dialogue at the early stages of Hydrogen Policy, and it was an informal body with an advisory role that involved 19 hydrogen-power stakeholders and included representatives of the research community, industry, public authorities and end-users [7]. The HLG recommended the creation of Hydrogen and Fuel Cell Technology platform (HFP), beginning with 2004 and after that was establishet a long-term approach at EU level for achieving critical mass in terms of scale, excellence and potential for innovation in the 7th Framework Programme (FP7) of the European Community (2007-2013) in the form of a Joint Undertaking (JU) on Fuel Cells and Hydrogen. From May 2014 was continued as a the second part initiative with funding under the Horizon 2020 Framework Programme under the name: Fuel Cells and Hydrogen Second Joint Technology (FCH 2 JU), where from 2018 JU launched the FCH-Regions Initiative to support regions across Europe in assessing the business cases for fuel cell and hydrogen applications and in mapping their local capabilities so that they can be exploited in the future. This initiative attracted 89 European regions and cities from 22 European countries which were actively working to shape their green energy transitions with hydrogen and fuel cells [8]. The period following the end of the FCH-Regions, have been launched in May 2019, the European Hydrogen Valleys Partnership (EHV-S3P) under the Smart Specialisation Platform. The EHV-S3P aims at facilitating exchanges of knowledge and practices between regions, strengthening the European Hydrogen value chains and promoting the concept of Hydrogen Valleys [8]. Fuel Cells and Hydrogen Second Joint Undertaking (FCH 2 JU) ceased operations on 29 November 2021, and its succesor Clean Hydrogen JU, was established on 30 November 2021 to take over its legacy portfolio and to continue developing the European value chain for safe and clean hydrogen technologies [9]. The Clean Hydrogen Joint Undertaking or Clean Hydrogen Partnership [10] is an unique public-private partnership supporting research and innovation (R&I) activities in hydrogen technologies in Europe. It builds upon the success of its predecessor, the Fuel Cells and Hydrogen Joint Undertaking, will help to achieve the 2030 energy and climate targets and most importantly to make climate neutrality possible by 2050 [11].

In Romania, there are some proposals for "Hydrogen Valleys" implementations, like Green Hydrogen @ Blue Danube and Hydro3D [12-14]. Developing the infrastructure necessary to accommodate hydrogen for various applications, remains a key challenge. Researchers, companies, and both local and national authorities are considering that mixing hydrogen with natural gas and transport of the mix in the natural gas pipeline networks without building new dedicated infrastructure, carries many potential benefits but also rises numerous challenges [15].

2. DESCRIPTION OF THE PROJECT

In order to create a “Hydrogen Valleys”, it is necessary to engage several decision-making factors, from private companies to research and development centers, to find an optimum, in terms of: hydrogen production, mixing the hydrogen with natural gas, transportation trought natural gas pipe network, storage of the mix of hydrogen with natural gas, using the technologies for separating hydrogen from natural gas, using the mix of hydrogen with natural gas in cogeneration systems, local hydrogen storage and transport and its valorification on the market, and all of this in a very specifically geographical region. Today, most hydrogen is produced using fossil sources (i.e., Gray hydrogen) and is used primarily in refining and chemicals sectors, but clean (i.e., Blue, Green or Pink) hydrogen is expected to play an important role in several new growth sectors, including power generation.

A geographical region, with exclusive specificity in the production of green hydrogen through chemical and/or electrochemical processeses (by alcaline electrolysis for example), is the Onesti town area, in Bacau county, where the complex of refineries and chemical processing of brine, through the company Chimcomplex from Borzesti village, Onesti town, has a green hydrogen production capacity of 6,000 tons/year [16], which can be an important step in achieving a new feasable so-called “Hydrogen Valley”. The advantage of alkaline electrolysis from brine water through ion-exchange polymer membrane technology is that the energy required to extract hydrogen is 46 times lower than the energy required to extract hydrogen from pure water by classical electrolysis [17]. The geographical advantage of Chimcomplex is given by the existence, only 20 km from the plant, of the salt extraction area from wells made in the salt massif by the dissolution method, in the Targu Ocna area, Slanic Moldova town. Through a 21.4 km pipe, the brine is transferred from the extraction area to Chimcomplex, stored in special tanks, and it is processed in order to extract chlorine, sodium hydroxide and hydrogen, through the alkaline electrolysis process. The salt caverns formed in this way will be used to store the mix of natural gas and hydrogen. In the table 1 [18] are given some capacities of such caverns made by dissolution technology and in the figure 1 below [19] it is shown a such cavern made in the salt massif with the shape made with a 3D sonar [20-21]. With the dedicated FLAC 3D software [22] for geotechnical analyses of soil, rock, groundwater, constructs, and ground support, will be analysed the displacements and the strains in salt mine rocks, because an imposed initial pressure of 30 barg, for an initial study. Pressure, temperature, and humidity may have detrimental impacts on the salin walls.

Table 1. Some closed wells in Târgu-Ocna and availability for H_2+DNG storage

Well no.	Variation of well flange elevation [cm]	Period of well conservation[years]	Cavern capacity [m^3]	Diameter [m]	Good for storage [yes/no]
S254	0	150	580,714.88	178	Yes
S255	-13.60	37	351,193.25	91.6	To Be Defined
S282	-14.10	35	105,416.82	44.6	To Be Defined

S251	-1.10	454	-	-	Yes
S268	-27÷-49	∞	-	-	Yes

a. The well 254 in conservation b. 3D model made with sonar

Fig. 1. The well 254 from zone Târgu Ocna, Slănic Modova town

The necessary volume of the cavern for storage the mix of natural gas with hydrogen considering an amount of 50 tons of hydrogen, and considerring a total pressure of the mix of 30 barg is done iteratively, taking into account the partial mass of hydrogen in the storage conditions at 30 barg of the mixture. The volume of the cavern is considered variable considering that the volume of brine is variable by extracting it from the cavity and sending it through the saltduct to the Chimcomplex. The total pressure of the mixture is given by the sum of the partial pressures of the components. The partial volume of the components will be 25% for H_2 and 75% for dry natural gas (DNG). Will be taken into consideration that the molar mass of the DGN will be the molar mass of the methane M_{DNG} = 16 [g/mol] as an initial aproximation. The universal gas constant R = 8,314 [J/(mol·K)]. The compressibility factor Z=1. The cavern temperature is considered constant and equal with T_{cav}=15°C (288.16 K). The gas constant of the mixture is given by the equation (1) below [23]:

$$\mathcal{R}_{mix} = \frac{\mathcal{R}}{M_{DNG} \cdot v_{DNG} + M_{H_2} \cdot v_{H_2}} = 665.12 \text{ [J/(mol·K)]} \quad (1)$$

The mass of the mixture is given by the general equation of state see below:

$$\mathcal{M}_{mix} = \frac{\mathcal{P}_{mix} \cdot \mathcal{V}_{mix}}{Z \cdot \mathcal{R}_{mix} \cdot \mathcal{T}_{cav}} \quad (2)$$

The partial mass of the hydrogen will be given by the equation (3):

$$m_{H_2} = \frac{M_{H_2} \cdot v_{H_2}}{M_{DNG} \cdot v_{DNG} + M_{H_2} \cdot v_{H_2}} = 0.04 \quad (3)$$

The partial mass of the DNG will be given by the equation (4):

$$m_{DNG} = \frac{M_{DNG} \cdot v_{DNG}}{M_{DNG} \cdot v_{DNG} + M_{H_2} \cdot v_{H_2}} = 0.96 \qquad (4)$$

The total mass of the hydrogen stored in the total volume V_{mix} is given by the equation (5):

$$\mathcal{M}_{H_2} = \mathcal{M}_{mix} \cdot m_{H_2} \qquad (5)$$

and is dependent on the iterated V_{mix} volume. The V_{mix} volume resulted from the iterations is about 77,280 m^3 for 50 tonnes H_2 stored in the mix with dried natural gas at 30 barg and 15°C at 25% H_2 and 75% DNG. It is observed that for a small amont of H_2 stored, the neeeded volume is quite great, in the proximity of 80,000 m^3. For example, at a volume of 500,000 m^3 of the cavern, the amount of hydrogen stored in mixture with dried natural gas is about 323.5 tonnes at 30 barg and 15°C for 25% H_2 and 75% DNG.

In the figure 2 is given a proposal for the circuit of the hydrogen in a supposed "Hydrogen Valley" located in the Onesti town area, in Bacau county. In the scheme can be observed that have been introduced some companies that have technologies dedicated for H_2 mixing with DNG, transportation of the mix of H_2 with DNG, local extraction of the H_2 stored in LOHC (Liquid Organic Hydrogen Carriers) system, local extraction of H_2 from H_2 with DNG mixture, storage of the H_2 with DNG mixture, compression and transportation of the H_2. The proposed H_2 transportation over the existing saleduct is possible also through subsequent investments, using a polyetilene pipe for 21.4 km and introduced into the cavern. Also, it is taken into consideration the storage of the hydrogen in DepoGaz cavities, where the storage capacities are at least 100 times the capacity of the greatest cavity from Targu Ocna zone [24]. The smallest capacity of DepoGaz is in Bălăceanca zone, with 50 million m^3 storage volume. Taking into consideration a maximum pressure of 63 bar for storage [25], the total capacity for H_2 storage in a such cavity is about 67,000 tonnes for 25% H_2 and 75% DNG mixture.

COMOTI – The Romanian Research & Development Institute for Gas Turbines [26], is a certified manufacturer for DNG compression packages, and in conformity with the INSEMEX (the legal authority for ATEX certification in Romania) rules, can use its certified packages for DNG compression for mixures of H_2 with DNG in proportion of 25% H_2 and 75% DNG without modifications for the existing ATEX certification. Also, for mix of gases that not exceed 25% of hydrogen, the gas group IIB it is not modified to gas group IIC [27-28]. The salt cavities above mentioned belongs to the National Salt Company SALROM [29], and have the capacities between 50,000 to 500,000 m^3. For mixed gas storage, the cavities need a permanent monitoring, periodic certification and certified personnel to serve the storage capacities indefinitely. Also, for the arrangement of the cavities to be able to allow gas storage, it is necessary to adapt them from the point of view of the wellhead cements used, the calculation of the caverns and their monitoring with authorized personnel, the most suitable being personnel with mining studies provided by the University from Petrosani, with long activity in the processing of coal deposits and others.

Man Energy Solution is coming with LOHC technology, that uses heat transfer oil as a carrier for hydrogen, thus allowing hydrogen to be stored under ambient conditions. The technology increase 3 times the amount of hydrogen that can be transported compared to standard pressurized containers and is a safe and efficient solution for storing and distributing hydrogen on a large scale [30].

DelGaz Grid can be also a potential partner in a such project as his pilot tests in-situ 20HyGrid, demonstrated that the mixing of H_2 with DGN is a fiable solution. The purpose of the project was both to analyze the compatibility and behavior of the elements of the existing natural gas distribution networks and the installations, respectively of the related devices, selected in the pilot project, to the mixture of natural gas with 20%v.v. (by volume) hydrogen, and to evaluate the the possibility of their conversion to the hydrogen - natural gas mixture. The test where made using steel pipes and also polyetilene pipes [31-32].

And finally, there is the problem of extracting hydrogen in the desired volume/mass quantities from the mixture of hydrogen with natural gas, so that it can be capitalized on the market. For this purpose the membrane technologies available at the Siqens company have been found, with its patented EHS (Electrochemical Hydrogen Separation) [33], that enable separation of the hydrogen from gases realizing a high-purity product gas for its capitalization.

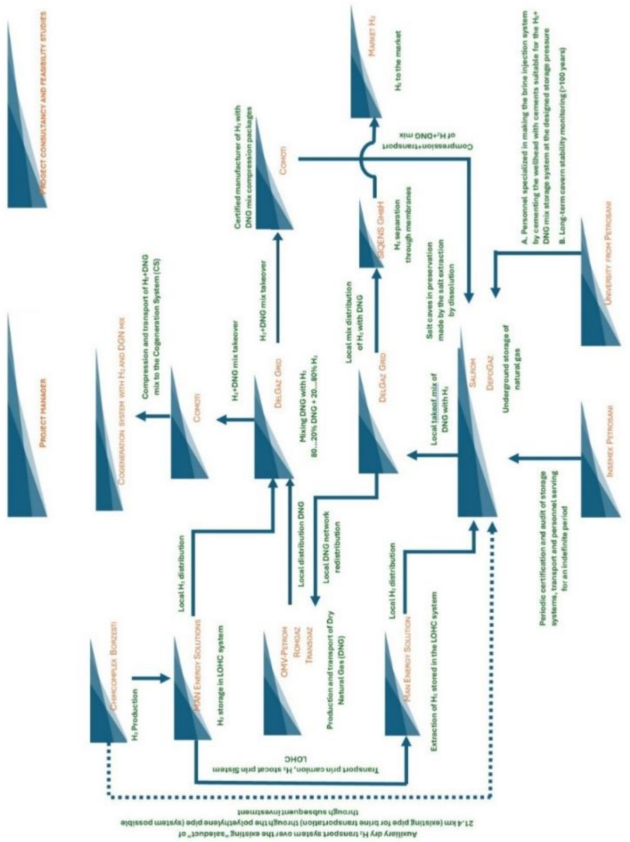

Figure 2. The scheme for the 3-rd proposed “Hydrogen Valley” in Romania

In the figure 2 above, have been made a theoretical scheme for a theoretical 3-rd “Hydrogen Valley” region, in Romania, utilizing the green power and green technologies for green hydrogen production, in the Onesti area, Bacau county, with some known companies, that can be involved in the project.

For a mixture of dry natural gas with hydrogen, the lower calorific value is calculated using the partial volume of the constituent elements. For the same volume of gas circulated thrtough the pipe, prior to the introduction of hydrogen into the natural gas, the calorific value of the mixture decreases, requiring an increase in the circulated flow rate to compensate the energy losses due to the hydrogen injection. For the natural gas that is a mixture of C_nH_m components + others, the calculations are done using the standard ISO 6976 [34].

For the mixture of H_2 + DNG can be used the same standard taking into account the calculated values for DNG. In the table 2 below are given the values needed for the calculations:

Table 2. Some values for H_2 and DNG properties in the H_2+DNG mixture

Component	ω (acentric factor)	v_i (%)	m_i (%)	ρ [g/Nm^3]	HcG_{0i}
DNG	0.011	75	96.01	669.07	890.27
H_2	-0.219	25	3.99	27.75	286.64

In the table 3 below are given the calculated values for the H_2+DNG mixture:

Table 3. The final values for the H_2+DNG mixture

Component	ω (acentric factor)	vi (%)	mi (%)	ρ [g/Nm^3]	HcG_0 [kJ/mol]	Z [-]
H_2+DNG	-0.04652	100	100	696.82	739.31	0.9986

HcG_{0i} are the individual lower calorific values and HcG_0 [34] is the calculated lower calorific value for the H_2+DNG mixture. The compressibility factor Z has been also calculated. From the calculations, to get the same value for the lower calorific value of the mixture compared with the lower calorific value of a given flow of DNG alone (0% H_2), it is necessary an increasing with 20.4% of the mixture flow with 25% H_2 and 75% DNG. Also, as volumetric flow is incresed for mixture and also as for H_2 compression the needed energy is higher, as the molecule is very small compared to other gases [23], the capacity of the compressors and coolers need to be higher than those used for alone DNG compression, and the expenses for such instalations increase.

3. SHORT CONSIDERATIONS ABOUT MIXING/DEMIXING AND TRANSPORTATION OF H_2 AND DNG IN ROMANIAN NATURAL GAS NETWORK

Delgaz Grid, an E.ON Romania’s distribution subsidiary, started in 2022 a pilot project to test the compatibility and operation of the use facilities and distribution system components with a mixture of hydrogen (H_2) and dry natural gas (DNG) with finalization in October 2024 (c.y.) [35], to show that is possible and safe to add 20%v.v. hydrogen to distribution networks and utility facilities of existing natural gas in Romania. The pilot station is created near Medias town, Sibiu county, Romania, where in 1925 have been instaled the first natural gas delivery measurement regulation station [36]. The demonstration showed that the use of the mixture in the distribution grid, installations and devices in households and other technical installations is technically possible and without additional risks. At the same time, the mixture has a lower concentration of polluting gases such as carbon monoxide and nitrogen oxide. Blend (mixing) limits depend on the design and condition of current pipeline materials, of pipeline infrastructure equipment, and of applications that utilize natural gas. Gaseous hydrogen has a signifcant impact on fatigue and fracture resistance of line pipe steels, especially on high-alloy steels, and, also, polyethylene pipeline materials are not fully understood and require additional testing to confirm their tolerance of hydrogen [37]. The main components of the existing natural gas distribution network are already prepared to take in hydrogen at maximum 30%v/v, and in the last step, after 2050, the network will be capable to takeover 100% v/v green hydrogen. Romanian Government has allocated over EUR 1 billion until 2030 from the European Union's Modernisation Fund and the National Recovery and Resilience Plan (NRRP or, in Romanian, PNRR) to support investments in the value chain of green hydrogen [38].

The first profile organization, in Romania and in Europe, under the name "Erste Siebenbuergische Erdgas Aktiengesellschaft – The First Transylvanian Company for Natural Gas Conduction", was established in 1912 at Turda town, Cluj County, Transylvania, Romania, its object of activity being natural gas transmission and exploitation of Sarmasel reservoir. The company commenced the building of a 55 km long methane gas transmission pipeline with a diameter of 153 mm, from Sarmasel to Turda, completed in 1914 [36], and now is belonging to Transgaz Romanian Company, as the operator of the natural gas transmission system, that provided for the integration of hydrogen from renewable and low-carbon sources into the natural gas transmission system in its development strategy [39].

The UK presents a case of domestic gas before 1967, containing 50% hydrogen, caming from gasifed coal [37]. In Germany, the gas pipeline network is hydrogen-ready, and suitable for the transport of hydrogen [40]. Portugal is expected to produce extremely cheap hydrogen owing to abundant renewables — and in some cases projects have already secured subsidies to reduce the cost of their green hydrogen and opened applications for its first tender for green hydrogen and biomethane to be blended into the country's public gas network [41] and so on. The FutureGrid closed-loop hydrogen test facility in northern England has completed Phase 1 of testing, successfully demonstrating the potential of Great Britain's gas National Transmission System (NTS) to transport blends of up 100% hydrogen [42]. There are many other countries in the world that have already implemented the mixture of hydrogen with natural gas in their distribution network between 5 and 30%. There is also a new metod for hydrogen separation and purification from mixtures of hydrogen and natural gas between 3 – 99% v/v by electrochemical technology, see figure 3, a SIQENS HT PEM stack (High Temperature Polymer Membrane) [43].

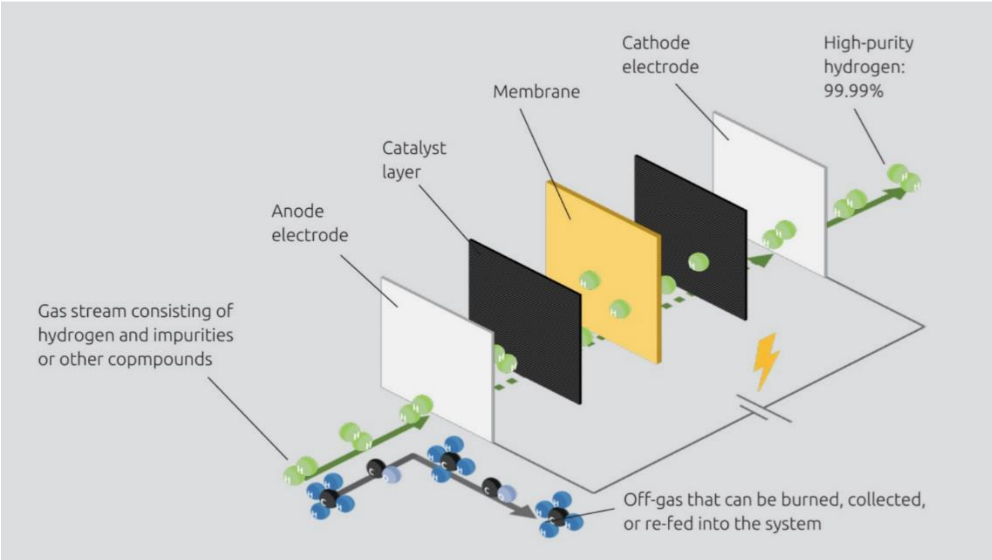

Fig. 3. Energy-efficient and scalable separation and purification of hydrogen from various gas streams

Energy consumption based on hydrogen content is given by the figure 4 below [43]:

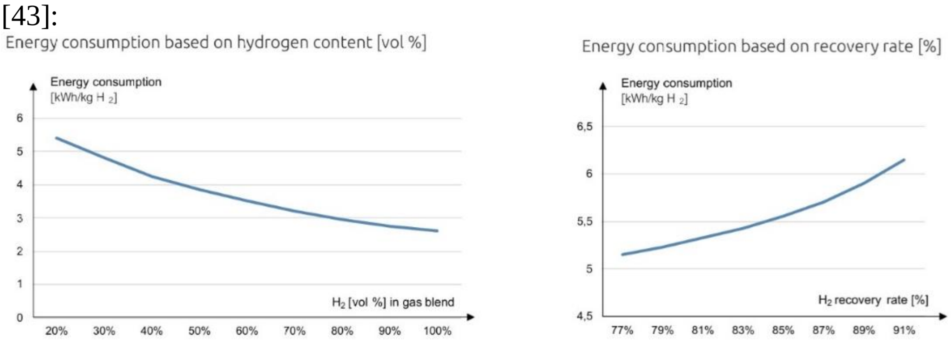

Fig. 4. Hydrogen separation from a mixture of hydrogen and natural gas

On-site separation and purification leverage the benefits of existing pipeline infrastructure or enable transportation via hydrogen carriers [43]:

- Hydrogen demixing - Local separation from mixtures within the natural gas grid
- Gas networks - Extraction of high-purity hydrogen from gas networks
- Hydrogen pipelines - Purification of hydrogen after long-distance transportation
- LOHC (Liquid Organic Hydrogen Carrier) technology [30] - Purification after dehydrogenation or reconversion

Generally, hydrogen technologies have been defined by standards, and even if they are at the beginning regarding large-scale use, the use of hydrogen is not at beginning, and the safety measures to reduce the risks are also covered by specific standards. The general problems that need to be solved soon as possible are the following: hydrogen producing stability, hydrogen transport, hydrogen storage, hydrogen mixing with natural gas, mixture transport, capitalization by utilizing the mixture as fuel in cogeneration systems, see Lazard studies [1, 2], or using it for householders in a maximum 20% see the achievements of DelGaz Grid company, and also, extracting of the hydrogen from the mixture and capitalizing it on the market.

In Romania as is shown in figure 5, Transgaz Company (Romanian NTS - National Transmission System) has identified specific locations where it is to carry out a pilot project for the transmission and use of natural gas - hydrogen mixture [39].

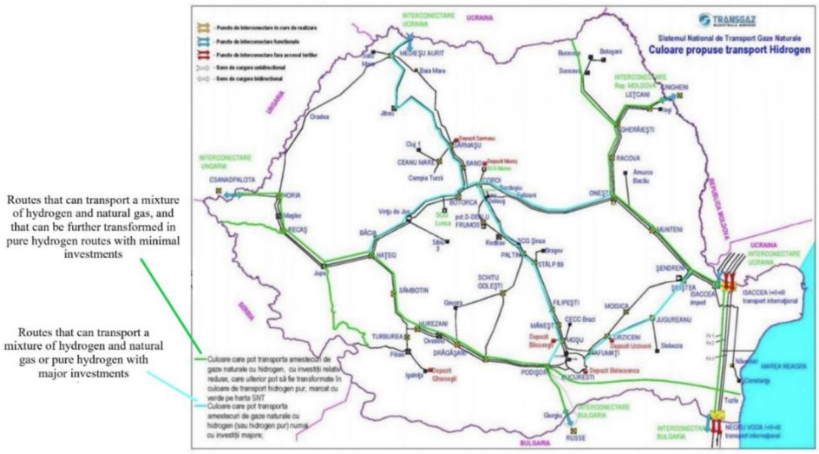

Fig. 5. Map of Romanian NTS routes proposed for hydrogen transport

As Romania sent its National Integrated Plan in the Field of Energy and of Climate Change 2021-2030 (NECP) to the European Commision [44], and as exist the European Climate Law where EU committed to reduce its net greenhouse gas emissions by at least 55% by 2030, with its 'Fit for 55' legislative package adopted [45-46], this types of proposed projects so-called "Hydrogen Valleys", have a strategical importance for Romania, and should be implemented as soon as possible in the Romanian value chain.

4. CONCLUSIONS

Romania has the possibility to produce hydrogen from the entire existing color palette, with the exception of white hydrogen which has not yet been identified as a geological source in Romanian deposits, except perhaps the extraction of it from natural gas depoits with a maximum of 5%vv H_2 composition, through membrane separation, see the above Siqens company technology [33, 43]. Also, there are technologies for H_2 production from black and brown color (from coal antracite/lighnite), from grey and turquoise (from natural gas) and blue (from natural gas and oil combined with carbon capture and storage/sequestration CCS) to green, yellow and pink/red/purple hydrogen made from regeneration sources [47], technologies that can be implemented at large scale for different purposes. In Romania there are some proposals regarding the creation of so-called “Hydrogen Valleys” see [13] and [14], but there are not yet implemented. The present work came with a scheme given in the figure 2 for a feasable “Hydrogen Valley”, with romanian companies with European know-how, and what is the most important, with romanian resourses and capacities. The green hydrogen production is assured in an enough amount by the Chimcomplex company that is increasing the production capacity by new alcaline electrolysers acquisitions [17], by Recovery and Resilience Plans [48]. In this way can be achieved a pilot project that will provide Romania with a first step towards the development of technologies related to decarbonization in the predetermined plan of 55% until 2030, 90% in 2040 and 100% in 2050, relative to 1990, provided as targets by the European Union [49]. Also, the possible involved companies have a very good background and excellent results in the hydrogen and natural gas processing.

Romania has a potential for about 3 million m^3 storage volume in salt caverns, and the volume is increasing. The importance of the salt caverns is given by the low permeability, supposed to give for H_2 a leakage less than 1% / year and for DNG a leakage less than 0.1% / year [50], or 10% / 10 years for H_2 and 1% / year for DNG, that means that in time, the procentage of H_2 will be lower in the mixture, but in the limits of the fesability of the project. The existing cavities have enough capacity for developing the desired “Hydrogen Valleys” projects to increase Romania's long-term energy security.

Future obiectives will be given by the increasing of the hydrogen procentage in the natural gas grid, up to 100%, this being a bold target at the level of Romania, but not impossible, at least at the local level of “Hydrogen Valleys”.

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DISASTER MANAGEMENT AND FIRST AID ELEMENTS IN THE CASE OF ACCIDENTS WITH EMISSIONS OF FLAMMABLE - TOXIC GASES - AN INTEGRATIVE LITERATURE REVIEW

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Abstract: *Natural and anthropogenic hazards generate numerous losses of human life and material damage every year, which directly affect the process of social and economic development. Over time, hazards changed their patterns, expanded and became more frequent, being increasingly difficult to predict. Under these conditions, efforts to prevent hazards and mitigate their impact on society are necessary as integral parts of sustainable development policies. In order to identify the stages of manifestation of a disaster, it is necessary to clarify some aspects regarding the assessment of risks and vulnerabilities, anticipating a response to an accident, assessing the dimensions of the event and last but not least aspects regarding rehabilitation and reconstruction if necessary. In the sub-chapter dedicated to the identification and characterization of toxic environments, the toxic gases with the highest degree of danger will be reviewed, their mechanisms in toxicological terms and the related defining characteristics, as well as the maximum admissible limits at different exposure times in accordance with the national legislation in force. The defining chapter of this scientific work will represent important aspects regarding the evaluation of patients exposed to toxic gas emissions, first aid elements as well as measures to secure victims exposed to toxic substances.*
The present work aims to provide information about disaster management, its phases and first aid elements in the case of certain specific situations

Key words: *disaster management, flammable - toxic gas emissions, victim assessment first aid elements*

1. INTRODUCTION

Hazard is a threatening event and represents the probability of occurrence in a certain period of a potentially harmful factor for humans, for the goods produced by them and for the environment.

Disasters are a permanent threat to sustainable development and generate numerous human casualties and material losses every year; at the same time, the beginning of this millennium is characterized by an increasing impact of human activities on the planet [1].

The frequency of the incidence of hazards and the increase in their magnitude has attracted the attention of the national and international communities in recent years. A number of institutions, intergovernmental organizations and non-governmental organizations worldwide have reviewed their approach to disasters and are working

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together to identify the best methods to prevent and reduce the impact of hazards/disasters on society.

Increasing the degree of development of a society can increase vulnerability in certain cases, such as: urban development (crowding, high density of buildings - earthquake risk, technological accidents), coastal development (flood risk, tsunami), transport investments (deforestation – risk of environmental degradation), investments in poor areas (risk of pollution), agricultural projects (risk of floods, desertification, pollution).

2. THE INTRINSIC ELEMENTS OF DISASTER MANAGEMENT

In order to identify the stages of manifestation of a disaster, it is necessary to clarify some aspects regarding the assessment of risks and vulnerabilities, anticipating a response to an accident, assessing the dimensions of the event and last but not least aspects regarding rehabilitation and reconstruction if necessary [2-4].

Assessing and assessing risks and vulnerabilities makes an estimate of the magnitude of each potential risk and the importance of that risk to the population and the environment. We try to quantify the probability of disaster risk, establish the acceptable levels of risk and calculate the potential losses (quantifiable - which are the economic costs and unquantifiable - the losses related to the human being) [5].

The objective of risk management is to connect all elements and actors in the disaster management system, to develop disaster mitigation tools based on prevention and intervention strategies, transfer and mutual exchange of knowledge, education and decision-making techniques. Disaster risk assessment is very important, given that hazards interact at different spatial and temporal levels, with development at local, regional and international levels. In addition to the individual study of potential hazards, a multidisciplinary understanding and an integrated analysis of the various processes is important, given that disasters are often complex. The assessment of the possible destruction of some systems, of the infrastructure, of the environment, of society is the basis of financial risk management, but vulnerability is still an insufficiently clarified concept from a scientific point of view [6]. A rigorous quantification is very difficult especially in relation to the indirect destructions that occur following a disaster – social destruction, cultural heritage, environmental systems.

Risk assessment methods are essential elements in the methodological effort to understand the potential effects of hazards on human activities and the environment.

The response to the disaster represents the totality of the actions taken by the authorities and the population in the face of the disaster. It includes warning, security, communication and information management, logistics and supply, post-disaster assessment, research and rescue of survivors, post-disaster assistance (assisting the population, maximizing the number of survivors, restoring essential services, rebuilding destruction) and operations management emergency.

The assessment of the disaster, which involves determining the impact of the disaster on society, is an interdisciplinary process and has as priorities the establishment of the needs for immediate emergency measures, for the rescue and life support of the survivors of the disaster and the identification of the possibilities to urgently restore the infrastructure, services and development. The assessment of the disaster is made taking into account various phases of the disaster: *Warning phase* (determining the population group for which measures are taken to protect life and facilities to mitigate the impact of a potential disaster and activate arrangements in the preparedness plan from the assessment perspective)[7,8]; *Emergency phase* (confirmation of the reported degree of emergency and estimation of destruction, identification, characterization and quantification of the population at risk of disaster, support for the definition of action priorities and the resources needed for immediate risk reduction, identification of local response capacity, including organizational resources, medical and logistical, support for the anticipation of serious future problems and support for the management and control of the immediate response); *The rehabilitation phase* (identifying the priorities of the affected population, identifying government policies for post-disaster assistance, estimating additional support from national and international sources for mitigation, recovery and monitoring the results of these measures); *The recovery phase* (determining the destruction of significant economic resources and their implications for development policy, assessing the impact of the disaster on current development programs and identifying new development opportunities created by the disaster).

Rehabilitation and reconstruction comprise the largest period of the post-disaster recovery phase. Rehabilitation is done in the period immediately following the manifestation of the disaster and is the transition phase between mitigation and reconstruction. The reconstruction period involves the full restoration of services and infrastructure, the construction of buildings, the restoration of destroyed infrastructure and, last but not least, the revitalization of the economy [9].

3. MULTIDIMENSIONAL CHARACTERIZATIONS OF TOXIC ENVIRONMENTS

Gases that can form toxic /explosive /flammable atmospheres will be presented/characterized from a physical-chemical point of view. Also, this section will review the toxicological mechanisms and at the same time the maximum admissible limits at different exposure times in accordance with the national legislation in force. Regardless of the tendency to change the composition of the air, an atmosphere must be ensured that excludes the danger of intoxication, explosion, occupational diseases, etc. The gaseous components that can appear in contaminated air are: non-dangerous (oxygen and nitrogen), toxic (hydrogen sulphide, nitrogen oxides, sulfur dioxide, ammonia, carbon dioxide, carbon monoxide) and, last but not least, explosive (carbon monoxide carbon, hydrogen sulphide as well as hydrogen).

Hydrogen sulphide (H_2S) is a colorless gas with a characteristic smell of spoiled eggs, which allows its detection even in very small concentrations in the air. It burns with a blue flame. In the working atmosphere, at a concentration of 4.5 ÷ 45%, it forms an explosive mixture with an ignition temperature of 370° C. The toxicity of H_2S is very high. The intoxication is due to its direct action on the central nervous system, which, after a first phase of stimulation, it depresses, death occurring by stopping breathing. The symptoms of poisoning depend on the inhaled concentrations: in the case of low concentrations, mucosal irritation occurs, in the case of higher concentrations, asphyxiation occurs. In a concentration of 0.1 ÷ 0.2 % death is instantaneous. Lower concentrations produce a sequence of quite characteristic phenomena. Signs of severe irritation of the conjunctiva of the eyes appear first, with severe redness and tearing, then burning and mucous nasal discharge, and an intense burning sensation in the pharynx. The irritating action on the mucous membranes of the respiratory tract triggers strong bouts of coughing with mucous expectoration, possibly bloody, and bronchopneumonia processes may subsequently develop. Asphyxiation symptoms also gradually set in, first dizziness and headache, unsteady gait and diarrhea appear. Later the breathing becomes shallow, the pulse quick, the blood pressure falls, and finally there is loss of consciousness and cessation of breathing [10]. After a short interval, the heart also stops. Organoleptic detection is completely insufficient, because precisely at high concentrations the smell loses its warning value, by inhibiting the olfactory receptor. Consequently, if the presence of hydrogen sulphide is suspected at a workplace, any activity must be organized with maximum caution. Individual protection must be ensured - on a case-by-case basis - with special filtering masks or with closed-circuit insulating devices. The maximum allowed concentration of hydrogen sulphide is 10 ppm.

Carbon monoxide (CO), often but improperly called "white gas", is a product of the incomplete combustion of solid, liquid or gaseous materials that contain carbon. The term "white gas" is inappropriate because carbon monoxide is a colorless and therefore invisible gas. It is also a tasteless and odorless gas with a density of 1,250 kg/m^3 and compared to air, under normal conditions of pressure and temperature, it is a little lighter, which is why in a stagnant atmosphere we always find it at the ceiling works. It is a gas that is difficult to dissolve in water and burns with a bluish flame. When mixed with air, it is explosive, at concentrations between 13 ÷ 74 % CO, with the ignition temperature of the mixture of 630 ÷ 810^0C, having the maximum intensity of the explosion at a content of 30 % CO. The causes of the appearance of carbon monoxide in contaminated air are: the operation of internal combustion engines; working with explosives and fires. Detecting this gas is very difficult because it has no color, taste, or smell, and for this reason it is a permanent potential danger to the health and even the life of all personnel. Carbon monoxide is a very strong and extremely dangerous poison for the body. This gas exerts its action by replacing oxygen from the combination with hemoglobin in the blood, a substance that normally absorbs oxygen from the air at the level of the lungs and delivers it in the form of oxyhemoglobin to the various tissues of the body. The affinity of carbon monoxide for hemoglobin is 200 - 300 times greater than that of oxygen. Therefore, if only a small amount of carbon monoxide is present in the air, hemoglobin will absorb it, preferring it to the existing oxygen. The compound formed by carbon monoxide with blood is known as carboxyhemoglobin. The importance of occupational poisoning with CO results from both the frequency (60% of occupational poisonings) and the severity of this disease, as CO causes more fatal accidents than all other toxic gases combined. Furthermore, since carbon monoxide and oxygen are in competition for blood hemoglobin, a decrease in the oxygen content of the breathed air will give carbon monoxide more chances to combine with hemoglobin [11]. Thus, exposure to an atmosphere poorer in oxygen, containing a given concentration of carbon monoxide, will produce a higher percentage of blood saturation with this gas, than an atmosphere with the same concentration of carbon monoxide, but with a normal content of oxygen. In acute intoxication without loss of consciousness (COHb below 50%), complete recovery takes place after a few hours to 1÷2 days. At a concentration of 66% COHb, death is imminent by depressing cardiac and respiratory activity. Above 70% COHb death is rapid and the skin color is cherry. In the case of carbon monoxide inhalation, the symptoms of poisoning depending on the percentage of carboxyhemoglobin are shown in the table no. 1 below.

Table 1. Symptoms of carbon monoxide poisoning

Saturation of hemoglobin with carbon monoxide [%]	**Symptoms of intoxication**
10	Without perceptible effects, possibly in the case of heavy work, breathing disorders may occur
20	Slight breathing disorders and heart palpitations occur
30	Headaches, irritability, fatigue, intellectual disturbances, vomiting
40 – 50	Headache, weakness, fainting on physical exertion
60 – 70	Fainting, and shortly after death
Peste 80	Death intervenes in moments

The symptoms of carbon monoxide poisoning are: headache (at the temples), then a feeling of heaviness in the head sets in, disordered breathing, walking becomes swaying with a feeling of lack of balance, vomiting, loss of consciousness. For the total saturation of the red blood cells in the body with carbon monoxide, a quantity of 1.1 liters of CO is required, but serious symptoms of poisoning with this gas can also appear when inhaling 0.3 liters of CO. At a concentration of 1% CO is fatal after a few breaths. CO poisoning can be late in nature. The maximum allowed concentration of CO is 20 ppm.

Ammonia (NH3) is a colorless gas, with a characteristic pungent and suffocating smell, easily soluble in water and slightly flammable, and when mixed with oxygen it is explosive. It causes irritation of the respiratory or digestive tracts depending on how it enters the body, the excitation of the central nervous system and the respiratory center, it irritates the ocular conjunctivae, and in high concentrations the skin [12]. In case of intoxication by inhalation in small concentrations, it causes irritation of the ocular conjunctivae and the bronchial mucosa. In cases of higher concentrations, ammonia can trigger an excruciating cough, foamy expectoration, cyanosis, glottic edema and pulmonary edema, subsequently bronchopneumonia sets in. The evolution can be rapidly fatal in cases of massive exposure (3000 mg/m3), either through respiratory arrest or pulmonary edema, with death in a few minutes. Bloody expectoration and bronchial irritation may persist for several months after severe exposure. Ammonia can cause serious eye problems, corneal ulceration and subsequently blindness. The skin is sensitive to ammonia: in a concentration of 1% in the air it causes irritation, if the skin is moist. A concentration above 3%, after exposure for a few minutes, can produce chemical burns with vesiculation. Poisoning by ingestion causes caustic lesions on the gastrointestinal tract. The maximum allowed concentration of ammonia is 20 ppm.

4. PRIMARY AND SECONDARY ASSESSMENT OF A VICTIM

Before any procedure related to the examination of the victim, it is essential to guarantee the safety of the rescuer, as well as the team and last but not least the victim [13]. The rescuer must make a quick and thorough survey to assess the existence of changes in the vital functions, which endanger the life of the victim. After this stage a secondary examination will be carried out, asking if there are any injuries that are not immediately life-threatening, but which require emergency care and stabilization for safe transport to the nearest hospital.

The primary examination aims to detect the existence of situations that may endanger the life of the victim, as well as the provision of adequate emergency assistance. In the main survey of the victim, the rescuer must, in the first phase, assess the state of consciousness and then check breathing.

Evaluation of the state of consciousness - A victim is aware if they react when stimulated. To do this, we gently shake the victim's shoulders and ask out loud: "Can you hear me?" / "Are you okay?". If the victim is unconscious, we must immediately call for other help. If unresponsive, the victim is unconscious and in potential danger of death.

Breath check - The first step in the breathing assessment is to clear the airway. Airway obstruction is a very serious situation, which can occur in unconscious victims by muscle relaxation, by the accumulation of secretions (vomit, blood, etc.) or by the presence of foreign objects, such as teeth, prostheses, food, soil, leaves, etc. After clearing the airway, approach the victim's face, analyze the chest while keeping the airway open. Check your breathing for 10 seconds, using the three steps (Figure 1): *Look* - if there is a vertical displacement of the chest; *Listen* - the flow of air passing into the victim's airways; *Feel* - the air exhaled by the victim.

Figure 1. Assessment of respiratory function

Secondary examination **-** After the end of the primary examination (detection and rescue in situations of immediate danger to life), the secondary examination begins.

The general objective of the secondary investigation is to detect situations that do not constitute an immediate danger to life, but could aggravate the victim's situation. The approach should be efficient, systematic and carried out in the following sequence: gathering information and assessing vital signs.

The collection of information is essential and aims to: To know what happened to the victim **-** in some situations it may seem obvious what happened, but talk to the victim, you may get information that divulges other causes; Identify the victim's main problem **-** not always what hurts the most is more obvious; Finding out the antecedents **-** the fact that he had previous diseases, or he has allergies to certain types of drugs. Questions for the victim: Name and age; What happened? (allows the identification of the characteristics of the event: time, type of accident, number of people, etc.); Have you ingested any substances?

The assessment of vital signs refers to the pulse, breathing and skin characterized by temperature, color and humidity. *The pulse* is a wave of blood generated by the heartbeat and propagated along the arteries; it is palpable in any area where an artery passes over a bony prominence. Pulse is the number of beats the heart makes in one minute. The specialist literature considers that a normal pulse in the case of a healthy adult, at rest, is between 60 and 100 beats per minute. In children, usually up to the age of one year, it is greater than 100 beats per minute; For children over one year old, the values are between 80 and 100 beats per minute. Changes in pulse frequency represent the important data for the medical team. A rapid pulse / weakness, may result from a state of shock with blood loss. A lack of pulse may mean a blocked or damaged blood vessel, or that the heart has stopped working (cardiac arrest). Normal breathing is done easily, without effort and without pain. The inhalation / exhalation set is called a ventilation cycle. The frequency of breathing can vary greatly, for an adult, it is usually between 12 and 20 times per minute. In evaluating the characteristics of the skin, the following must be taken into account: temperature, color and the presence / absence of moisture. Normal body temperature is around 37 °C. The skin is largely responsible for the thermoregulation process, namely the heat that radiates through the blood vessels and the evaporation of water in the form of sweat. Cold, clammy skin may indicate a response to the sympathetic nervous system, namely trauma or blood loss (shock). Exposure to cold usually produces cold and dry skin. Warm, dry skin can be caused by a fever, an illness, or be the result of excessive heat exposure, such as heat stroke. The color and presence/absence of moisture depends primarily on the presence of blood circulating in the subcutaneous blood vessels. Pale, white skin indicates inadequate circulation and is seen in victims of shock or myocardial infarction [14]. A bluish color (cyanosis) is observed in heart failure, airway obstruction, and also in some cases of poisoning. It can also be a red color, in certain stages of carbon monoxide (CO) poisoning and in case of stroke.

5. MOBILIZATION OF VICTIMS - SIDE SAFETY POSITION

Unconscious, untraumatized victims should be placed in the lateral safety position (figure 2) to maintain a clear airway [15].

Kneeling next to the victim clear the airway by hyperextending the head and lifting the chin. Place the victim's nearest arm at right angles to the body, and the forearm bends upwards. Cross the victim's other arm across the chest with the back of the palm on the victim's cheek. Lift the victim's knee (the one opposite the rescuer) by pulling it up and keeping the leg on the ground. Grasp the opposite shoulder (to the rescuer) with one hand and the patient's knee with the other hand. Turn the victim sideways to the rescuer; and make sure they are resting on their knees and elbows, rearrange the head into hyperextension and open the victim's mouth. Reassess the situation and monitor the victim until medical personnel arrive.

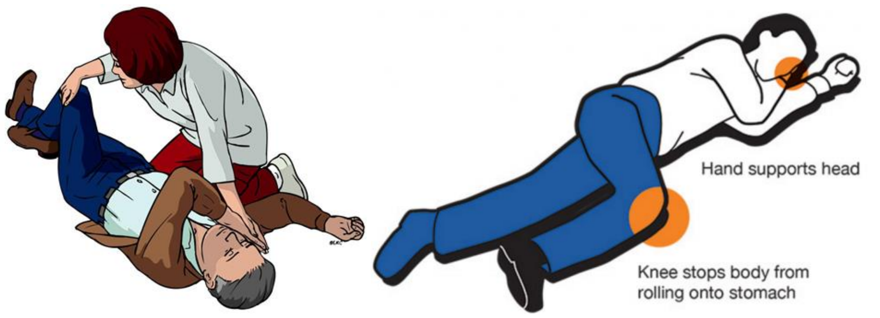

Figure 2. Lateral safety position

6. CONCLUSIONS

Disasters are a constant threat, causing many human casualties and material losses every year; at the same time, the beginning of this millennium is marked by an increasingly significant impact of human activities on the planet.

A paradox of contemporary society's attitude towards disasters should also be mentioned: the allocation of material and human resources for the prevention and reduction of the effects of disasters has greatly increased, but at the same time the development of human society represents a favorable factor for the triggering of disasters and/or for amplifying their consequences.

Greater emphasis is placed on disaster prevention by involving all stakeholders in disaster risk management activities.

It is necessary for everyone to know how to proceed in order to save the life of someone who is in danger or to reduce the negative consequences on the injured person.

First aid is not given only in very serious cases. Sometimes, certain minor accidents can present complications that can later lead to serious health problems in the injured person, if they are not given adequate medical assistance.

A quick action in the event of an accident can save a person's life or prevent injuries from getting worse.

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COMPUTATIONAL STUDY OF HYDROGEN DISPERSION, FIREBALL AND EXPLOSION FOR ENHANCED INFRASTRUCTURE SAFETY

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Abstract: *Hydrogen plays an important role in the energy transition and has an impact on production, transmission, storage, utilization up to district heating and the integration of electric and gas transmission systems. By converting the electric energy into hydrogen, it can be easily transported with (and stored in) parts of the existing natural gas transmission network. Safety is a crucial issue to be addressed in this case, since accidental hydrogen releases present significant risks, particularly with the growing implementation of hydrogen infrastructure. In can be mentioned that there has been a lack of comprehensive investigation into hydrogen leakage scenarios, especially under complex real-world conditions. This study addresses this gap by modeling the dispersion of hydrogen gas, fireballs, and explosions based on various scenarios. The study employs consequence modelling software to analyze hydrogen leakage, vapor dispersion, and subsequent fires and explosions. Factors such as flammable quantity and wind speed are analysed for their impact on accident outcomes. The results show that both the dispersion distance of hydrogen and the thermal radiation distance of fireballs increase with larger quantities of flammable substance and higher wind speeds. This thorough numerical study of hydrogen leakage provides valuable quantitative insights, serving as a crucial reference for facility siting and design to mitigate the risk of hazardous events.*

Key words: *hydrogen, leakage, explosion, risk, safety*

1. INTRODUCTION

The global energy transition is increasingly reliant on innovative technologies in electrical engineering and energetic systems to address the pressing challenges of sustainability, efficiency, and safety. Hydrogen has emerged as a cornerstone of this transition, owing to its potential to decarbonize a wide range of sectors, including transportation, industry, and power generation. Its ability to be produced from renewable sources and utilized in fuel cells, emitting only water, positions hydrogen as

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a clean and versatile energy carrier. Integrating hydrogen into existing natural gas infrastructure facilitates its transport and storage, making it a pivotal element in the energy transition.

However, the deployment of hydrogen infrastructure brings forth significant safety concerns, particularly regarding accidental releases. Hydrogen's low molecular weight and high diffusivity result in rapid dispersion, which can lead to hazardous conditions such as fires and explosions. Addressing these safety challenges is crucial for the successful integration of hydrogen technologies within the broader energy system.

PHAST (Process Hazard Analysis Software Tool) is a critical instrument for consequence modeling in this context. Widely used in the field of energetic technology, PHAST provides comprehensive capabilities for simulating and assessing the impacts of hazardous material releases, including gas dispersion, fires, and explosions. This software is invaluable for analyzing complex scenarios involving hydrogen leaks, enabling detailed examinations of variables such as leak hole size, wind speed, and wind direction.

Recent advancements in hydrogen safety research have focused on various aspects of hydrogen behavior and risk mitigation. The work of some authors highlighted the significant influence of environmental factors on hydrogen dispersion in urban environments [1]. Also, there have been explored the dynamics of hydrogen-air mixture explosions in confined spaces, emphasizing the critical role of hydrogen concentration and ignition sources [2]. Recent research works have provided experimental data on hydrogen jet fires, contributing to more accurate predictive models [3].

Further contributions in the field of the paper are related to the effect of obstacle configurations on hydrogen dispersion and explosion in urban settings, revealing the significant impact of obstacles on dispersion characteristics and explosion overpressure [4]. Recent research works also focus on the mitigation strategies for hydrogen explosions, investigating venting and barrier systems to reduce explosion impacts in industrial environments [5]. There have also been analyzed the thermal radiation effects of hydrogen jet fires, providing essential data for determining safety distances and emergency planning [6].

Despite these advancements, there remains a gap in comprehensive investigations that consider multiple factors simultaneously under real-world conditions. This study addresses this gap by employing PHAST to model hydrogen dispersion, fireballs and explosions based on various scenarios. By examining the interplay between flammable substance quantity amd wind speed, this research provides a holistic understanding of hydrogen hazards. The findings offer quantitative data crucial for guiding facility siting and design, ultimately enhancing the safety of hydrogen infrastructure.

By advancing our understanding of hydrogen leakage dynamics, this study contributes significantly to the body of knowledge on hydrogen safety. It supports the safe deployment of hydrogen infrastructure, thereby facilitating its role in the global energy transition and addressing the innovational challenges in electrical engineering and energetic technology.

2. MATERIALS AND METHODS

2.1. Regulatory framework

The safe deployment and operation of hydrogen infrastructure are governed by a robust regulatory framework in both the European Union (EU) and Romania. In the EU, the Directive 2014/94/EU on the deployment of alternative fuels infrastructure [7] and the Regulation (EU) No 79/2009 on type-approval of hydrogen-powered motor vehicles set out comprehensive safety standards for hydrogen technologies [8]. These regulations address various aspects of hydrogen production, storage, transportation, and utilization, emphasizing the need for rigorous safety measures to mitigate the risks associated with hydrogen use.

In Romania, national regulations align closely with EU directives. The Romanian Energy Regulatory Authority (ANRE) oversees the implementation of hydrogen safety standards, ensuring compliance with EU norms. This regulatory body sets out specific regulations regarding the approval of technical regulations on the design and execution of hydrogen installations and safety requirements for hydrogen storage facilities [9]. These regulations mandate stringent safety protocols, including risk assessments, emergency response plans, and regular inspections to prevent accidents and ensure the safe handling of hydrogen.

2.2 Computational Tools and Software

To assess the potential hazards associated with hydrogen leakage, dispersion, fireballs, and explosions, this study employs the Process Hazard Analysis Software Tool (PHAST) version 8.4. PHAST is a comprehensive consequence modeling software widely used in the field of process safety and risk management. It is capable of simulating a variety of hazardous scenarios, providing detailed analyses of gas dispersion, fire, and explosion phenomena.

2.3 Modeling Scenarios

The study models several scenarios to evaluate the behavior of hydrogen under different conditions. The scenarios include variations in hydrogen quantity, wind speed, and wind direction, which are critical factors influencing the dispersion and impact of hydrogen releases.

- Scenario: Simulations are conducted for ”Catastrophic rupture” scenario of a pressure tank, containing different quantities of hydrogen.
- Wind Speeds: wind speeds of 2 m/s, 5 m/s, and 10 m/s are considered to examine their effects on hydrogen dispersion and fire behavior.

2.4 Simulation Parameters

The following parameters are used in the PHAST simulations:

- Storage pressure: 200 bar, representing a typical pressure in hydrogen storage systems.
- Temperature: Ambient temperature set at 20°C.
- Relative humidity: 50%.
- Hydrogen Properties: Standard properties of hydrogen gas are utilized, including its diffusivity, flammability limits, and thermal radiation characteristics.

3 CONSEQUENCE MODELLING

3.1 Input data

Table 1 below provides outlines on the input data for three simulation cases using the PHAST software to analyze the consequences of catastrophic rupture scenarios. The simulations aim to determine the worst-case radii for dispersion, radiation (fireball), and explosion. For all cases, the simulation scenario is a catastrophic rupture involving hydrogen (H2) in its gaseous state. The hydrogen is stored at a pressure of 200 bar and a temperature of 20°C. Atmospheric conditions are defined with Pasquil stability class F, indicating a stable atmosphere, a relative humidity of 50%, and a solar radiation flux of 0.5 kW/m².

Table 1. Table title 10p TNR

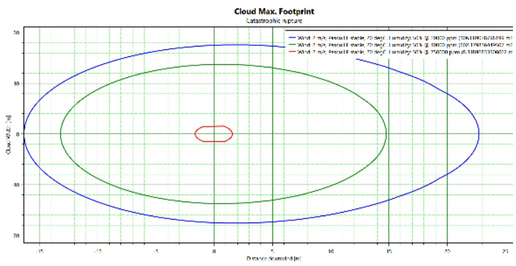
	Case 1			**Case 2**			**Case 3**		
Simulation scenario	Catastrophic rupture								
Material	H2								
State	Gaseous								
Pressure (bar)	200								
Storage temperature (ºC)	20								
Mass inventory (kg)	72.34			289.39			578.79		
Volume inventory (m^3)	5000			20000			40000		
Wind speed (m/s)	2	5	10	2	5	10	2	5	10
Pasquil stability	Class F - stable								
Relative humidity (%)	50								
Solar radiation flux (kW/m^2)	0.5								

In Case 1, the mass inventory of hydrogen is 72.34 kg, stored in a volume of 5000 m³. The wind speeds considered for this case are 2 m/s, 5 m/s, and 10 m/s. For Case 2, the mass inventory increases to 289.39 kg, and the storage volume is 20000 m³, with the same wind speeds of 2 m/s, 5 m/s, and 10 m/s. Case 3 involves a mass inventory of 578.79 kg and a storage volume of 40000 m³, again with wind speeds of 2 m/s, 5 m/s, and 10 m/s.

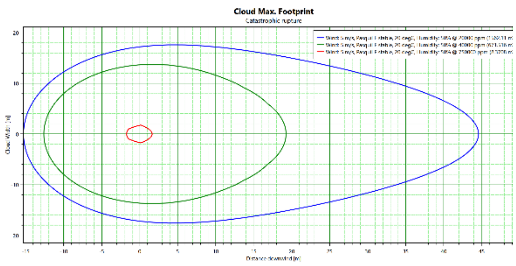
The objective of these simulations is to obtain the worst-case radii for three key outcomes: the dispersion of hydrogen gas in the atmosphere, the thermal radiation radius from the fireball resulting from the rupture, and the overpressure radius from the explosion. The provided input data will be used to run PHAST simulations and analyze the catastrophic rupture of hydrogen storage, focusing on the dispersion patterns, fireball radiation impact, and explosion pressure zones under different wind speeds.

3.2 Dispersion

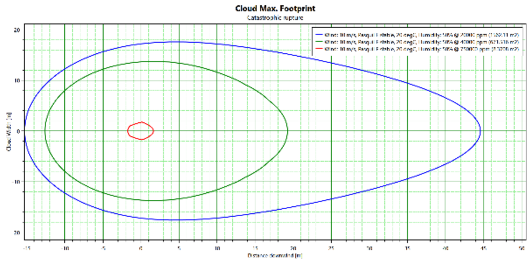
Accurate modeling and prediction of hydrogen dispersion are critical for evaluating potential risks and designing effective safety measures because, when released into the atmosphere, hydrogen rapidly disperses due to its low molecular weight and high buoyancy. PHAST employs sophisticated mathematical models to simulate this atmospheric dispersion of hydrogen. These simulations incorporate a range of variables, including the rate of hydrogen release, wind direction and speed, atmospheric stability, and local topography. By taking these factors into account, PHAST can provide detailed insights into the spatial distribution and concentration of hydrogen over time. This comprehensive information is essential for hazard assessment and developing strategies to mitigate risks associated with hydrogen releases under various environmental conditions. Taking all the relevant input data (Table 1) and parameters into consideration, there have been performed the consequence modellings for the three theoretical accident cases. The dispersion charts for the simulated cases are shown in Figure 1, Figure 2 and Figure 3.



a) wind speed 2 m/s

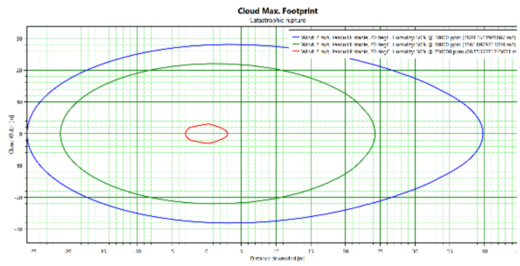


b) wind speed 5 m/s

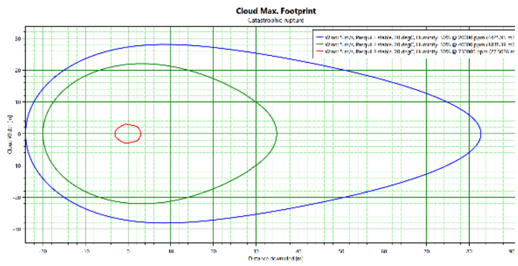


c) wind speed 10 m/s

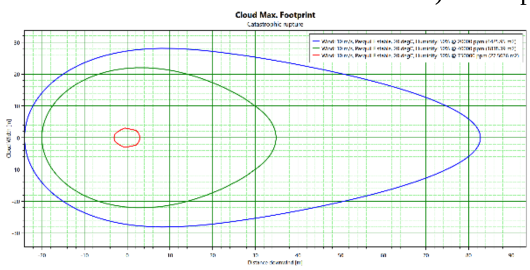
Figure 1. Cloud maximum footprint – case 1



a) wind speed 2 m/s

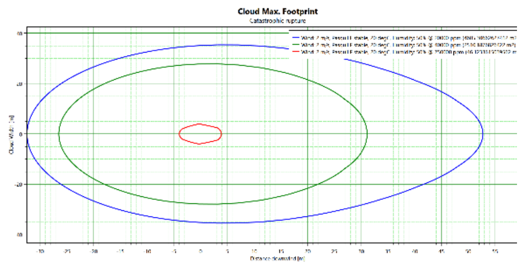


b) wind speed 5 m/s

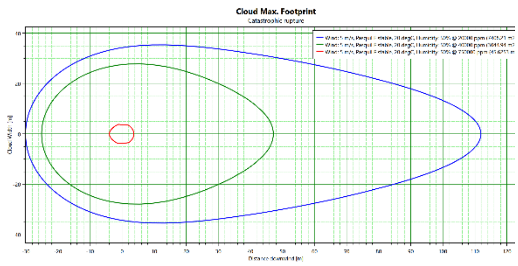


c) wind speed 10 m/s

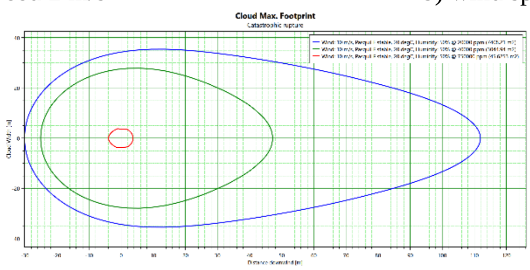
Figure 2. Cloud maximum footprint – case 2



a) wind speed 2 m/s



b) wind speed 5 m/s

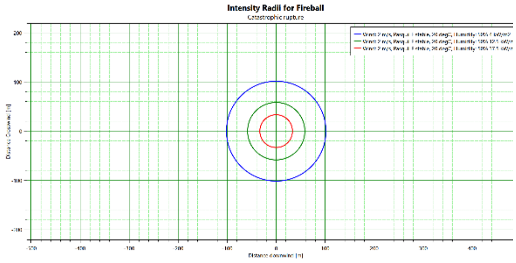


c) wind speed 10 m/s

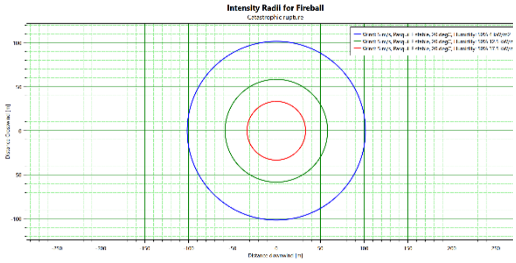
Figure 3. Cloud maximum footprint – case 3

3.3 Fireball

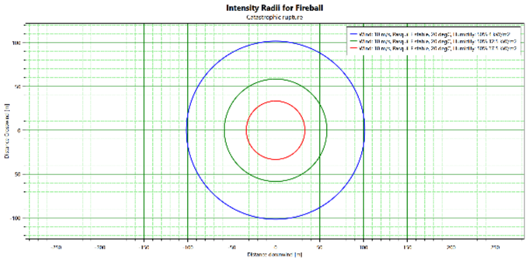
In the event of a catastrophic rupture of the H2 storage tank, the large amount of hydrogen released can be ignited by sources such as open flames, sparks, or electrical equipment. This ignition can create a fireball, a rapidly expanding and intensely burning mass of flames. The fireball emits intense heat radiation, posing thermal hazards to nearby structures, equipment, and personnel. Results of the simulations for the three cases taken into account are presented in Figures 4, 5 and 6.



a) wind speed 2 m/s

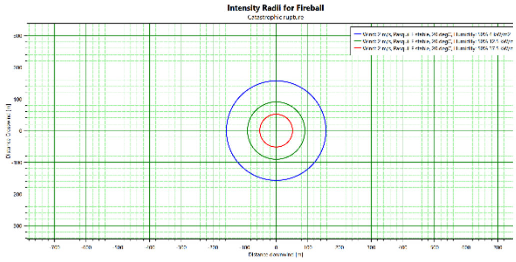


b) wind speed 5 m/s

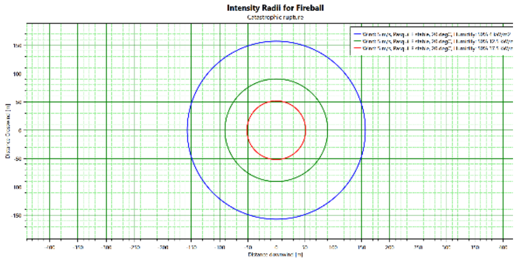


c) wind speed 10 m/s

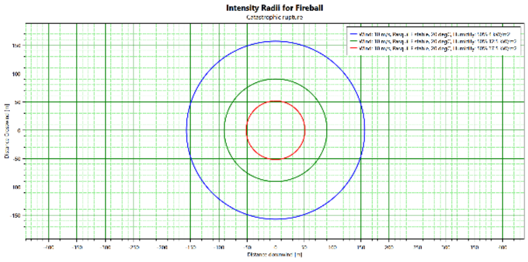
Figure 4. Intensity radii for fireball – case 1



a) wind speed 2 m/s

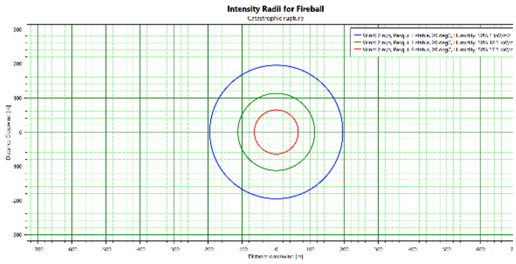


b) wind speed 5 m/s

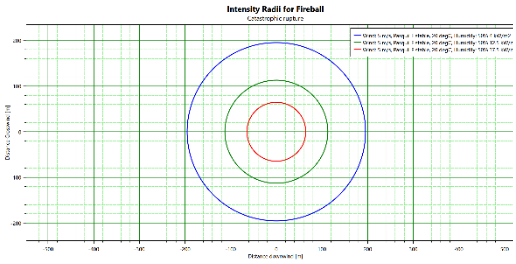


c) wind speed 10 m/s

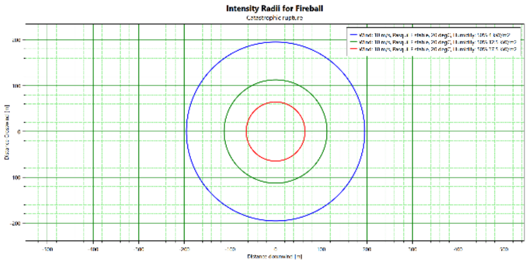
Figure 5. Intensity radii for fireball – case 2



a) wind speed 2 m/s



b) wind speed 5 m/s

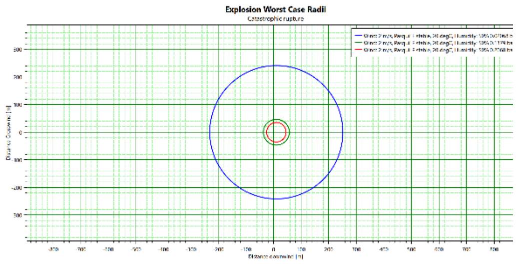


c) wind speed 10 m/s

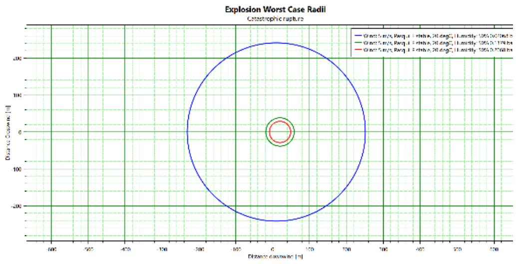
Figure 6. Intensity radii for fireball – case 3

3.4 Explosion

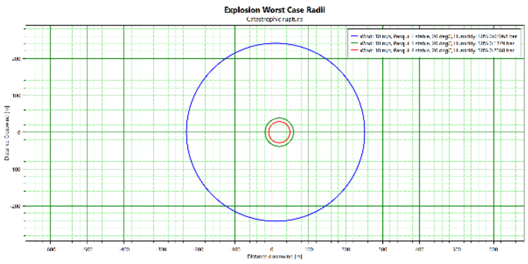
A catastrophic rupture followed by ignition can produce an explosion, generating severe blast effects, including overpressure waves, fragmentation of the tank, and potential projectiles. These effects can cause severe damage to nearby structures and endanger people in the vicinity. Results highlighting the explosion worst case radii for the three theoretical cases presented are shown in Figures 7, 8 and 9.



a) wind speed 2 m/s

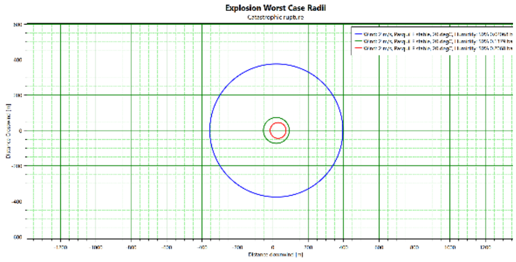


b) wind speed 5 m/s

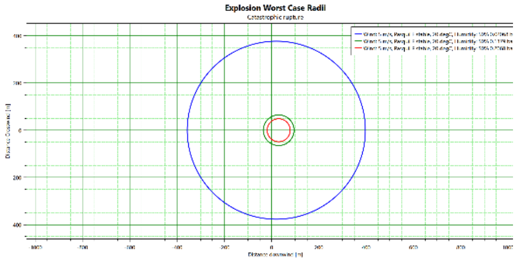


c) wind speed 10 m/s

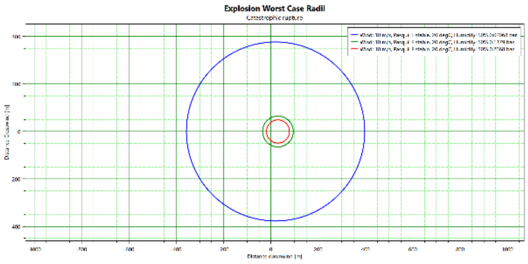
Figure 7. Explosion worst case radii – case 1



a) wind speed 2 m/s

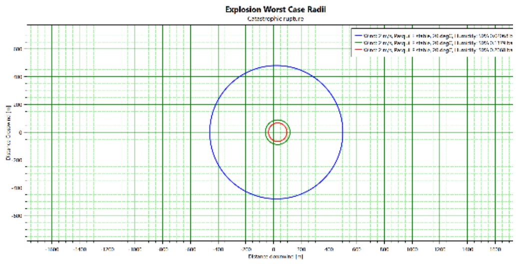


b) wind speed 5 m/s

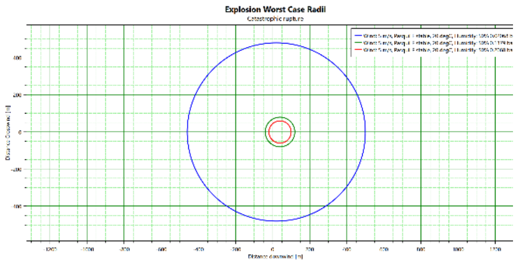


c) wind speed 10 m/s

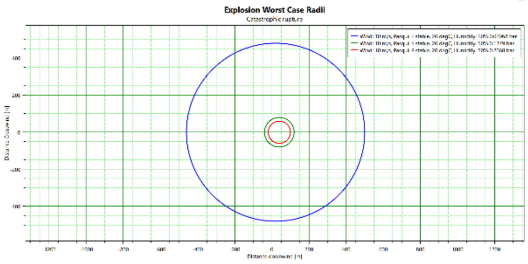
Figure 8. Explosion worst case radii – case 2



a) wind speed 2 m/s



b) wind speed 5 m/s



c) wind speed 10 m/s

Figure 9. Explosion worst case radii – case 3

4. CONCLUSIONS

This study presents a detailed computational analysis of hydrogen dispersion, fireball, and explosion scenarios using the Process Hazard Analysis Software Tool (PHAST). The findings provide critical insights into the safety measures necessary for the deployment of hydrogen infrastructure.

The simulations revealed that the dispersion distance of hydrogen gas increases with both larger quantities of the flammable substance and higher wind speeds. This highlights the need for comprehensive risk assessments considering environmental conditions when designing hydrogen storage and handling facilities.

The study showed that the thermal radiation distance from fireballs expands significantly with larger hydrogen quantities and higher wind speeds. This necessitates the establishment of sufficient safety zones around hydrogen infrastructure to protect personnel and equipment from thermal hazards.

The results indicated that the overpressure distances resulting from hydrogen explosions also increase with higher wind speeds and larger hydrogen inventories. This underscores the importance of implementing robust explosion mitigation strategies, including structural reinforcements and effective emergency response plans, to minimize the impact of blast effects on surrounding areas.

The quantitative data generated by this study can inform regulatory frameworks by defining safety standards and guidelines. Ensuring adherence to these regulations is crucial for the safe deployment and operation of hydrogen technologies.

While this study provides valuable insights, further research is recommended to explore additional variables such as ambient temperature, humidity, and real-world obstacle configurations. Experimental validation of the simulation results would enhance the reliability of the findings and support the development of more accurate predictive models.

By addressing the safety challenges associated with hydrogen leakage, this research contributes significantly to the safe integration of hydrogen into the global energy transition. The findings offer a critical reference for industry stakeholders, policymakers, and safety professionals committed to advancing hydrogen infrastructure safety.

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IMPACT OF THE PRESENCE OF HYDROGEN ON TYPE TESTING OF PRESSURIZED HOUSINGS

Gabriela PUPAZAN[1], Marius DARIE[1], Tiberiu CSASZAR[1], Alexandru BELDIMAN[1]

Abstract*: Hydrogen is an explosion hazard in potentially explosive atmospheres because of its ability to form flammable and explosive mixtures with oxygen in the air over a wide range of concentrations. Equipment protected against explosion by the pressurized enclosure type of protection is designed for use in potentially explosive atmospheres such as hydrogen. The first part of the paper highlights the explosion hazard and defines aspects of explosion protection. The second part of the paper describes the principle of protection by pressurized enclosures and the classification of pressurized equipment. The last part of the paper is the analysis from the point of view of the impact of the presence of hydrogen in the hazardous atmosphere on the type of tests to which the equipment must be exposed. An important conclusion of the paper is that, although in principle explosion protection by pressurized enclosure is not influenced by the flammable substance present in the hazardous atmosphere, the type tests to which equipment protected in this way must be subjected must take account of the presence of hydrogen and use the appropriate helium purge and dilution tests.*

Keywords*: pressurized equipment, explosive atmosphere, risk of explosion, hydrogen, type tests.*

1. INTRODUCTION

Hydrogen technologies are undergoing a period of significant growth as they are planned for widespread introduction into the power generation and production industries.

The use of hydrogen in the industry is not new, but the increasing impact, in terms of the number of potential users and the incidence of the area, may raise alarm bells by increasing the magnitude of the field of manifestation of the likelihood of hazardous situations in terms of explosions.

Awareness of the explosion hazard [1] is essential to be able to take early precautionary measures, including the selection of appropriate explosion-protected equipment.

Equipment intended for use in potentially explosive atmospheres containing hydrogen gas falls within the scope of Directive 2014/34/EU on ATEX products [2]. Such equipment is subject to a conformity assessment procedure as provided for in the Directive.

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Hydrogen is a highly flammable gas and can form explosive mixtures even at low concentrations in air.

The use of equipment in hazardous areas requires strict procedures to be followed due to the risk of explosion [3] due to the presence of hydrogen.

The presence of hydrogen influences hazardous atmospheres both through the qualification of the explosion subgroup and the temperature class. Additionally, due to the low relative density compared to air, a different distribution of concentrations per height will be implied, being higher in the upper parts.

Substances causing explosive atmospheres are classified into explosion groups. Hydrogen is among the gases classified as having the highest risk of ignition from an electrical source, namely group IIC. But it has a self-ignition temperature of 560 °C, which corresponds to temperature class T1.

The prevention of an explosion by limiting the ignition sources is implemented by explosion-protected equipment [2].

The "pressurization" or "pressurized enclosure" method of protection is based on maintaining a constant positive pressure of air or a protective gas, inside the enclosure to prevent the possibility of an explosive mixture entering the pressurized enclosure near the components/equipment [4], [5] and [6].

In this way, a pressurized enclosure makes it possible to use equipment without explosion protection in zones 1, and 2 with EPL Gb or Db and 21 and 22 with EPL Gc or Dc.

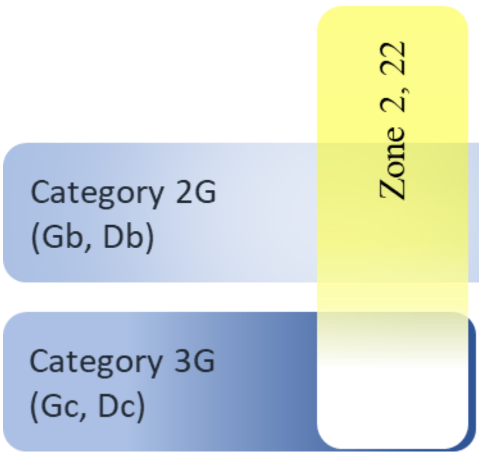

Figure 1. Protection category /level - area correlation

Pressurized enclosure protection is an effective and flexible solution for explosion prevention in hazardous industrial environments and is particularly suitable for applications involving hydrogen, due to the characteristics of this flammable gas.

To be accepted the equipment must be subjected to rigorous testing. By carrying out these tests for the use of hydrogen, manufacturers, and users can be assured that explosion-protected equipment with pressurized enclosure type protection is safe and suitable for use in such environments.

To analyze the test requirements in terms of the impact of hydrogen on equipment intended to operate in such atmospheres, several factors must be considered [7].

2. MATERIALS AND METHODS

For the safe use of technical equipment in general and electrical equipment in particular in potentially explosive atmospheres, explosion protection must be used.

Confirmation of the suitability and eligibility of explosion protection is done by certification. Certification in addition to the assessment stage with the relevant standards also requires practical confirmation of the relevant properties by testing.

The presence of hydrogen in explosive atmospheres has a varied impact on the tests to which equipment must be subjected in the certification process.

Equipment must be tested to ensure that no component exceeds the maximum allowable temperature during normal and abnormal operation. In addition, appropriate heat dissipation and thermal protection measures must be taken.

Because pressurization explosion protection is based on the implementation of an effective separation between the hazardous atmosphere and the parts that could lead to its ignition, the gas and vapour subgroup does not influence the explosion protection so much by the type of pressurization protection but the temperature class and zone index have a greater impact.

About suitability for different hazardous areas, this type of protection is divided into three levels of protection (pxb, pyb, and pzc) which are chosen according to the equipment protection level (EPL) required for an external gaseous explosive atmosphere (Mb, Gb or Gc), whether there is a possibility of internal release and whether the equipment inside the pressurized enclosure is likely to cause ignition.

Pressurization as a type of protection depends on the fulfillment of specific pressurization conditions [8] monitored and validated by so-called safety devices. In addition, because these safety devices are electrically powered and operate even when specific pressurization conditions are not met, they must be protected against explosion by other types of protection as required by the hazardous atmospheres in which the pressurized enclosure is located.

In addition, pressurized enclosures and their connecting components must be designed to withstand the maximum pressure of the pressurization or venting system and be designed to minimize the ingress of flammable gases, flammable vapors, and dust.

For test confirmation of explosion protection, the internal atmosphere of the pressurized enclosure shall be monitored at various points where it is assumed that the test gas is most likely to persist and in the vicinity of equipment which may be a source of ignition and which is outside the normal dilution zone of the pressurized enclosure.

Of all the relevant standards the "General requirements" standard applies to all equipment intended for use in explosive atmospheres.

Certain specific requirements covered by this standard are partially applicable or not applicable as specified in the relevant standards for the types of protection.

In the following, we will analyze the tests required by this standard from the point of view of the impact of the presence of hydrogen, as the presence of hydrogen may influence certain tests due to its unique properties such as low molecular mass and ease of ignition.

Tests that are not affected by the presence of hydrogen are:

- impact resistance;
- drop test;
- degrees of protection (IP) provided by the enclosures;
- thermal tests;
- temperature measurement;
- thermal shock test;
- ignition test for small components;
- torsion test for insulated passages;
- thermal endurance to heat;
- cold thermal endurance;
- resistance to ultraviolet radiation;
- continuity of earth connection;
- capacitance measurement;
- verification of the nominal fan parameters and alternative qualification of elastomer sealing rings.

The tests, specified in the general standard [5], significantly influenced by the presence of hydrogen in the hazardous atmosphere are: the verification of the surface resistance of parts of housings made of non-metallic materials and the transferred load test.

The tests required by the specific standard for the type of pressurized enclosure protection [4] which are not affected by the presence of hydrogen are:

- leak test other than static pressurization;
- static pressurization leak test;
- tests for a non-defective container system;
- overpressure test;
- non-defectibility test;
- overpressure test for a container system with limited clearance.

The presence of hydrogen, being a specific gas, does not influence the results of these tests as they focus on the physical and functional aspects of the housing and associated systems.

The tests required by the specific standard for the type of pressurized enclosure protection [9] significantly influenced by the presence of hydrogen are:

- pressurized enclosure in which the protective gas is air;
- pressurized enclosure in which the protective gas is inert gas;
- pressurized enclosure in which the protective gas may be air or inert gas with a density equal to the density of air ±10%;
- filling test for a pressurized enclosure protected by static pressurization;
- purge and dilution tests for a pressurized enclosure with an internal source of venting;
- pressurized enclosure in which the flammable substance has less than 2% (v/v) oxygen and the protective gas is an inert gas;

- pressurized enclosure with continuous circulation pressurization, container system with less than 21% (v/v) oxygen, and the shielding gas is an inert gas;
- pressurized enclosure in which the flammable substance is not a liquid, pressurized by continuous circulation, and the protective gas is air.

3. RESULTS AND DISCUSSIONS

The analysis revealed a specific distribution of tests influenced mainly by the presence of hydrogen in the hazardous atmosphere.

The diagram in Figure 2 shows the distribution of tests specified by the general requirements standard and the specific standard according to the type of tests.

The diagram in Figure 3 shows the distribution of the number of tests influenced mainly by the presence of hydrogen in the hazardous atmosphere according to the general requirement standard and the specific standard for the type of pressurized enclosure protection.

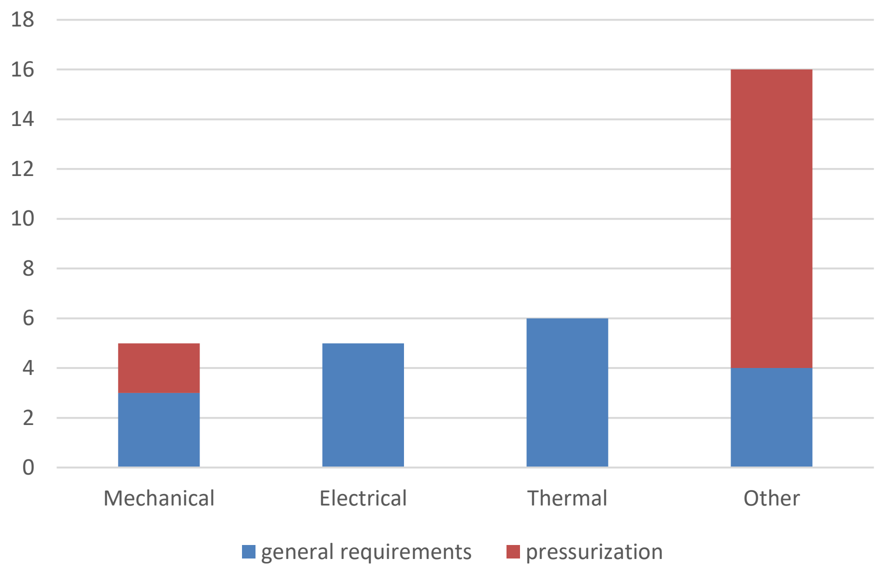

Figure 2. Types of tests

Analysis of the impact of explosive air-hydrogen atmospheres on the test characteristics of equipment intended for use in such atmospheres by the relevant standards: general requirements and pressurization, revealed a large variability.

The largest impact in terms of several tests influenced is the type of pressurization protection. This is due to tests that depend on relative density.

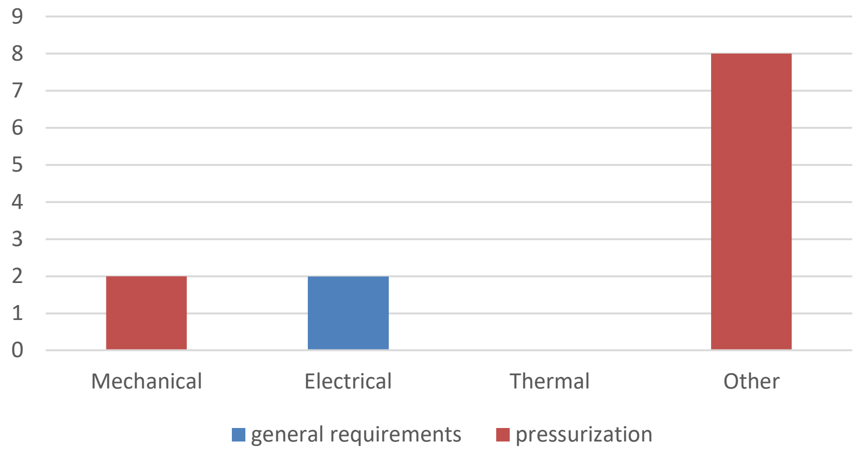

Figure 3. Tests were influenced mainly by the presence of hydrogen in the hazardous atmosphere

The analysis carried out specifically addresses the tests to be carried out on equipment intended for use in potentially explosive atmospheres, but there are also assessment requirements in the relevant standards for such equipment that are influenced by the presence of hydrogen.

4. CONCLUSIONS

The presence of hydrogen in the hazardous atmosphere influences the tests required by the general standard and significantly, the specific standard for the type of pressurized enclosure protection. Analysis of these influences has shown that many tests are affected mainly due to the very low relative density of hydrogen to air, but also due to its increased sensitivity to ignition from electrical sources.

Thus, several 12 tests influenced by the presence of hydrogen in the hazardous atmosphere were identified. Of these, two are mechanical tests, two are electrical tests and eight are tests specific to the pressurized enclosure protection type such as the filling test and the purge test.

Although explosion protection by pressurized enclosures is effective irrespective of the flammable substance in the hazardous atmosphere, the presence of hydrogen requires specific adapted tests. Purging and dilution tests must be rigorous and use helium to simulate the behavior of hydrogen, thus ensuring that protected equipment is safe and functions as required even under the most adverse conditions.

5. ACKNOWLEDGMENTS

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ENSURING THE PROTECTION AGAINST ATMOSPHERIC DISCHARGES OF TECHNICAL INSTALLATIONS OPERATING IN ENVIRONMENTS WITH THE RISK OF POTENTIALLY EXPLOSIVE ATMOSPHERES GENERATED BY HYDROGEN

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Abstract. *The presence of flammable/combustible substances in industrial premises leads to the occurrence of the risk of explosion. In general, flammable/combustible substances can include many of the raw materials, intermediate products, final products as well as waste products from the normal manufacturing process. All these flammable/combustible substances, when mixed with air, generate potentially explosive atmospheres that pose a risk of explosion in the presence of ignition sources. Among the sources of ignition, capable of initiating explosive atmospheres, such as those generated by hydrogen mixed with air, are atmospheric discharges. To prevent the risk of explosion and ensure an appropriate level of protection, technical installations operating in environments with the risk of potentially explosive atmospheres must be protected against atmospheric discharges. The work essentially aims to deal with aspects related to ensuring protection against atmospheric discharges of installations operating in spaces with the risk of potentially explosive atmospheres, including those generated by hydrogen, at the same time identifying and analyzing the methods and technical solutions that can be applied to prevent the risk of explosion, protecting technical installations and consequently ensuring the highest level of security.*

Key words: *risk of explosion, atmospheric discharges, explosive atmospheres, flammable/combustible substances, technical installations.*

1. INTRODUCTION

In general, within the technical installations where flammable/combustible substances are processed, transported, stored, there is a risk of the appearance and formation of potentially explosive atmospheres as a result of their release from the existing release sources.

An important role in the appearance and formation of a potentially explosive atmosphere is represented by the concentration and quantity of the released substance. Potentially explosive atmospheres can form in the immediate vicinity of the source of release from flammable gases and vapors originating from a technological installation provided that these substances remain unignited at the point of release or at a certain distance from the source of release depending on the composition, physical characteristics respectively environmental conditions.

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In general, potentially explosive atmospheres are formed by gases lighter than air such as hydrogen, methane, the production of an explosion in this case being rarer as these gases migrate to the upper parts of the technological spaces or disperse very quickly [1].

A space where potentially explosive atmospheres can occur in concentrations high enough to require special precautions to protect the health and safety of workers participating in the work process is considered hazardous. For these places, the term dangerous areas Ex. is usually used in the specialized literature.

Since in the case of technical installations there is a risk of potentially explosive atmospheres from flammable/combustible substances processed, transported, stored within the various processes that take place, these technical installations must be designed, operated and maintained in such a way that all releases of flammable/combustible materials , and consequently the extent of hazardous areas, be kept to a minimum in terms of frequency, duration and quantity, regardless of whether the operation is normal or not.

Where there are explosive atmospheres in the presence of sources of ignition, there is a risk of the initiation of these atmospheres and consequently the production of combustion and/or oxidation reactions.

The initiation of preformed explosive atmospheres within technical installations, inside technical equipment or around them, due to the release of various flammable/combustible substances can occur as a result of the presence of an ignition source.

However, it should be noted that the presence of an ignition source at the same time as an explosive atmosphere is a necessary but not sufficient condition. In order to produce the initiation of an explosive atmosphere, it is not enough that the ignition source is present, but it is necessary that it has the necessary energy to be able to initiate the respective explosive atmosphere.

Ignition sources that have the energy necessary to initiate explosive atmospheres are known as effective ignition sources. Among the sources of ignition that can initiate an explosive atmosphere are also atmospheric discharges.

In the situation where lightning strikes in an explosive atmosphere, there is always an ignition, there is also the possibility of ignition caused by the high temperature reached by the devices that receive the atmospheric discharge, namely the lightning rods [2].

In the case of an atmospheric discharge, high currents flow from the place where the lightning strikes, which can produce sparks in the vicinity of the point of impact.

In the conditions given to avoid the production of an explosion as a result of the initiation of explosive atmospheres by means of atmospheric discharges, a solution consists in the application of technical solutions to prevent these discharges from occurring in an explosive atmosphere.

Therefore, in order to ensure the highest level of security in the technical installations where flammable/combustible substances are processed, transported, stored, it is necessary to ensure protection against atmospheric discharges by applying methods and technical solutions that prevent the risk of explosion, protect technical installations and last but not least to ensure the safety and health of the participants in the work process.

2. ASPECTS RELATED TO THE USE OF EQUIPMENT AND TECHNICAL INSTALLATIONS IN ENVIRONMENTS WITH A RISK OF EXPLOSION

2.1. Responsibilities regarding the assessment risk of explosion generated by the installations used in environments with a risk of explosion

Legislation in force applicable to the field of Ex., regulates the obligations and responsibilities of persons involved in the design, manufacture and use, including maintenance, repair and decommissioning of equipment.

For the Ex., field, two European Directives, also known as ATEx Directives, are representative, which regulate the placing on the European market of products intended for use in potentially explosive atmospheres, respectively their safe use, namely:

- Directive 1999/92/EC of the European Parliament and the Council of 16 December 1999 regarding the minimum requirements for improving the protection of the health and safety of workers exposed at potential risk of explosive atmospheres [3];
- Directive 2014/34/EU of the European Parliament and of the Council of February 26, 2014 on the harmonization of the legislation of the member states regarding equipment and protective systems intended for use in potentially explosive atmospheres [4].

In addition, at the national level, the attestation of installations upon commissioning and periodically is regulated by the Normative of May 2, 2007 regarding the prevention of explosions for the design, installation, commissioning, use, repair and maintenance of technical installations operating in potentially explosive atmospheres, indicative NEx 01-06 [5].

According to the ATEx Directives, the responsibility of assessing the risk and taking appropriate protective measures to ensure an acceptable level of security rests with both equipment manufacturers and their users.

In fact, in the production phase under the manufacturer's responsibility, designers of equipment and protection systems, third-party bodies for tests/evaluations in the regulated or voluntary field may be involved.

In the use phase, the designers of the installations, those who assemble the equipment from the composition of the technical installations, the operators, the physical or legal platforms that ensure the inspection and maintenance, the first, second or third part, explosion risk assessors, as well as the bodies of control, ability for market surveillance, labor protection, environment.

Of particular importance is the competence of all the people involved in various phases of the activities they carry out in the ATEX field, the competence that must be proven.

2.2. The requirements of the ATEX Directives regarding the assessment of products from the point of view of the risk of explosion

Directive 2014/34/EU, transposed in GD 245/2016, regulates the obligations of manufacturers of protective equipment and systems intended for use in potentially explosive atmospheres. Included in the scope of the directive are safety devices, control devices and regulating devices intended for use outside of potentially explosive atmospheres, but which are necessary or contribute to the safe operation of protective equipment and systems with respect to explosion risks.

According to Directive 2014/34/EU, transposed into national legislation by GD 245/2016, the introduction to the market and/or commissioning of Ex products (equipment, protection systems and Ex devices) is allowed only if they do not endanger the safety and health of people or as the case may be, of domestic animals or goods, when they are properly installed, maintained and used according to their intended purpose.

This implies that Ex equipment, protection systems and safety devices meet the essential health and safety requirements set out in annex no. 2 of the Directive that are applicable to them taking into account the intended use.

Intended use within the meaning of the Directive means the use of equipment, protection systems and devices in accordance with the group and category of the equipment and with all the information provided by the manufacturer, which is necessary for the safe operation of the equipment, protection systems and devices.

It can be generally stated that this compliance with the essential health and safety requirements of Directive 2014/34/EU is imperative to ensure explosion protection of protective equipment and systems.

The requirements take into account potential or existing hazards that may arise during the design or construction phase. Also, in accordance with the provisions of the ATEx Directive 2014/34/EU, the notion of intended use is also of major importance.

According to the standards and norms specific to the field Ex., technical installation means a combination of two or more technical equipment that have already been put on the market independently by one or more manufacturers.

Technical equipment that is part of an installation intended for use in environments with a risk of explosion must meet the requirements of Directive 2014/34/EU. The connecting elements of technical equipment, part of an installation, do not fall within the scope of Directive 2014/34/EU except to the extent that they are part of the equipment itself or of the assembly put on the market by the manufacturer.

The Directive does not regulate the installation process. In general the installation of these types of equipment will be subject to legal requirements either specified in the workplace directives or in the national legislation of the member states.

In conclusion, the installation of technical equipment falls under the responsibility of the user who must make an explosion risk assessment which will also include the connecting elements as provided by art. 2.4 of Annex II of Directive 1999/92/EC transposed into our legislation by GD 1058/2006, namely:

- the plant, equipment, protective systems and all associated connecting devices must only be put into operation if the explosion protection document allows their safe use in an explosive atmosphere.

2.3. Classification of hazardous area Ex., generated by flammable/combustible substances processed, transported, stored within technical installations

Installations where flammable/combustible materials are handled or stored must be designed, operated and maintained so that all releases of flammable materials, and consequently the extent of hazardous areas, are kept to a minimum in terms of frequency, duration and quantity, regardless of whether the operation is normal or not.

A space in which explosive atmospheres can occur in such high concentrations as to require special precautions to protect the health and safety of the workers involved is considered hazardous. These spaces are known as hazardous areas or hazardous areas Ex.

The classification of dangerous areas is a method of analysis and classification of the environment in which explosive gaseous atmospheres can occur, with the aim of facilitating the correct choice and installation of technical equipment that can be used without danger in this environment, taking into account the explosion groups and of the minimum ignition temperature of gases (equipment temperature classes).

It is very important that the classification of hazardous areas is carried out by people who know the properties of flammable/combustible materials, processes and equipment, consulting, whenever necessary, security personnel, electricians and other specialists in the field. In practice, in most cases where flammable/combustible materials are used, it is difficult to guarantee that an explosive gaseous atmosphere will never occur.

Also, it can be difficult to guarantee that electrical equipment will never generate an ignition source. Therefore, when the presence of an explosive gaseous atmosphere is highly probable, resort will be made to the use of technical equipment with a low probability of generating an ignition source.

On the other hand, when the probability of the presence of an explosive gaseous atmosphere is low, it will be possible to use technical equipment made according to less rigorous standards.

Below are some examples of zoning encountered in practice [6].

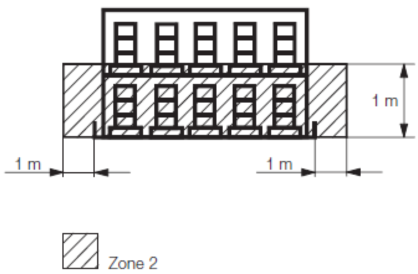
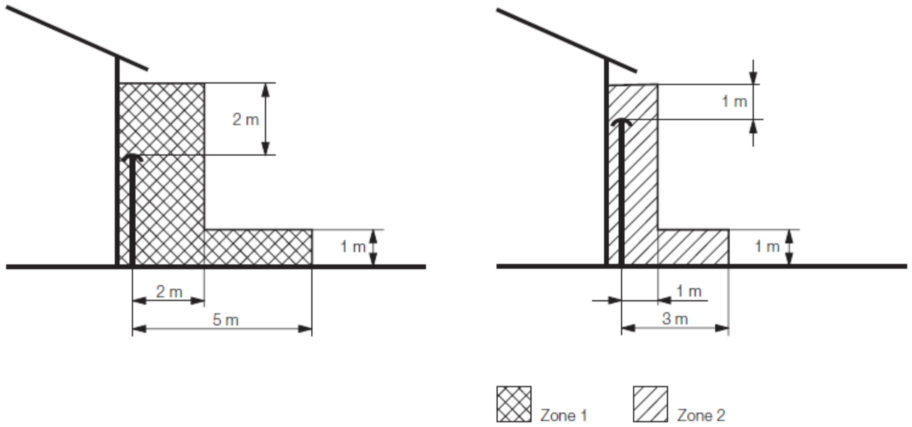


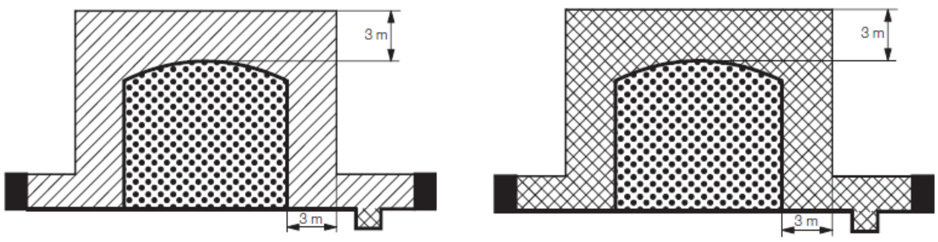
Figure 1. External storage of solvents



Freely communicating pressure compensation

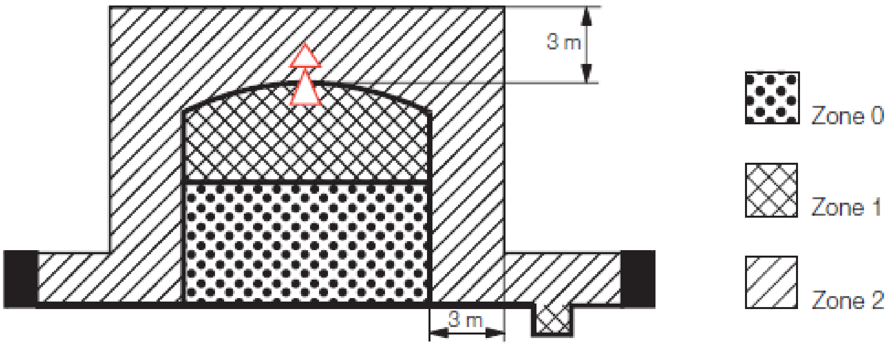
Pressure-vacuum or automatic valve systems

Figure 2. The pressure equalization line of a storage tank for highly flammable liquid substances



Tank with fixed roof (with gas compensation)

Tank with fixed roof (with pressure relief valve)



Membrane tank (natural ventilation above the floating membrane)

Figure 3. Storage in large tanks (over 250 m^3) for highly flammable liquids with a flash point < 30ºC

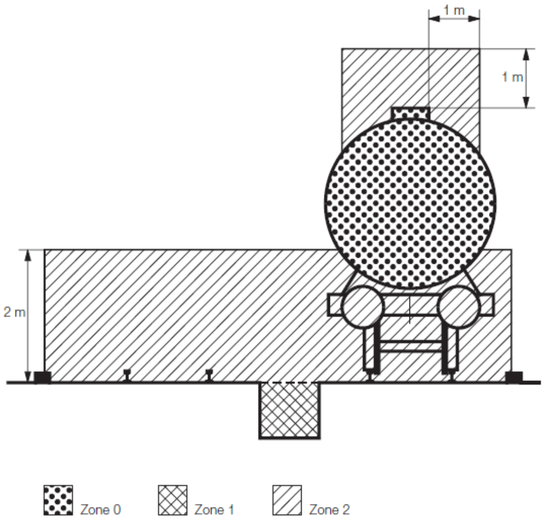


Figure 4. Emptying point (without filling) for tank wagons in which highly flammable liquids are transported

3. ATMOSPHERIC DISCHARGE PROTECTION OF TECHNICAL INSTALLATIONS IN EXPLOSIVE ENVIRONMENTS

Atmospheric discharges represent one of the active sources of ignition, capable of initiating explosive atmospheres generated by the presence of flammable/combustible substances mixed with air, the result of which is the production of an explosion and/or fire.

Therefore, in order to prevent the occurrence of an explosion and/or fire, the protection of equipment and technical installations, where explosive atmospheres are present, must be ensured against atmospheric discharges.

The protection of equipment and technical installations operating in environments with a potentially explosive atmosphere, against atmospheric discharges, is ensured by means of a protection system that generally consists of an external system and an internal protection system.

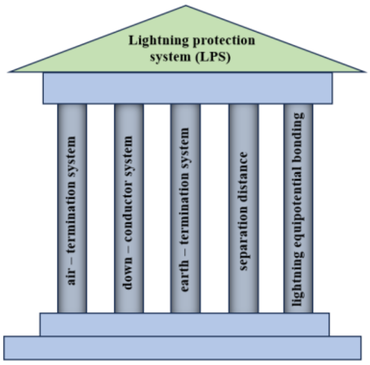


Figure 5. Components of a lightning protection system

The functions of the external lightning protection system are [7]:

- interception of direct lightning strikes through an air terminal system (rods, catenary wires, meshes made of conductors);

- the safe conduction of the lightning current to the ground by means of a system with a down conductor;

- distribution of the lightning current through an earth termination system.

Instead, the role of the internal lightning protection system is to prevent dangerous sparks inside the structure. This is done by establishing equipotential bonding or maintaining a separation distance between the components of the lightning protection system and other electrical conductors within the structure.

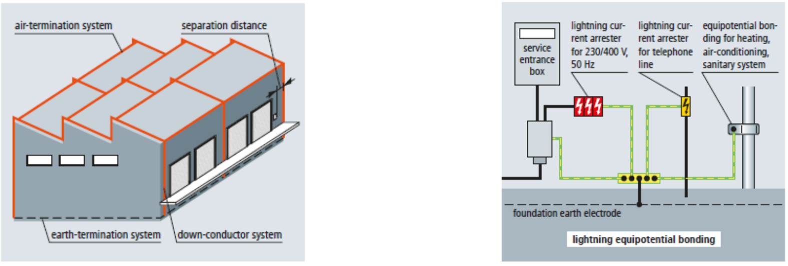


Figure 6. Lightning Protection System (LPS)

In most cases, the external lightning protection system can be attached to the structure to be protected. However, there are also situations when the thermal and explosive effects at the point of impact, or on the conductors that carry the current generated by the atmospheric discharge, can cause damage to the structure, situations in which an externally isolated atmospheric discharge protection system is applied.

Typical examples of such situations include structures with combustible covering, structures with combustible walls, and areas at risk of explosion and fire. Also an externally isolated atmospheric discharge protection system can be considered when the susceptibility of the contents guarantees the reduction of the radiated electromagnetic field associated with the current pulse generated by the lightning in the discharge conductor [7].

At the same time, natural components of conductive materials, which will always remain in/on the structure and will not be modified such as for example interconnected reinforcing steel, the metal frame of the structure, etc., can be used as parts of a protection system against atmospheric discharges.

In order to ensure the protection against atmospheric discharges of structures and technical installations, the correct positioning of air terminal systems is very important, in this regard there are several acceptable methods to be used in determining the position of the air terminal system, namely the protection angle method, the rolling sphere method, mesh method.

In this regard, capture components installed on a structure shall be located at corners, exposed points and edges (especially at the upper level of the structure) in accordance with one or more of the previously mentioned methods.

The rolling sphere method is suitable in all cases. The angle method of protection is suitable for buildings of simple form, but is subject to height limitations of air terminal systems, and the mesh method is a suitable form of protection where flat surfaces need to be protected.

In the case of structures, installations containing solid explosive material, the design of protection against atmospheric discharge should take into account the sensitivity of the material in the configuration in which it is used or stored, and an externally isolated atmospheric discharge protection system should be used.

The equipment, respectively the structures contained entirely in a steel metal casing with a thickness of 5 mm or 7 mm for aluminum structures, can be considered as protected by one of the natural systems (metal components of the roof of the construction, metal parts such as ornaments, railings, pipes, etc.) [8].

Where possible, all parts of the external lightning protection system (arresting components and discharge conductors) must be at least 1 m away from a hazardous area. Where this is not possible, discharge conductors passing within 0.5 m of a hazardous area should be continuous or their connections made by compression fittings or by welding.

Ensuring protection against atmospheric discharges of structures, technical installations where zones 2 and 22 exist may not require additional protection measures. For metal production facilities such as for example external columns, reactors, containers containing zones 2 and 22 thickness and material as follows steel (galvanized steel) 4 mm, titanium 4 mm, copper 5 mm, aluminum 7 mm, air terminal system and earth termination system are not required, instead the installations must be grounded [8].

In the case of technical installations where zones 1 and 21 exist, to ensure protection against atmospheric discharges, the requirements for zones 2 and 22 apply with some additions, depending on the existing situation, namely if there are isolated parts in the pipes, the operator must determine measures of protection and in the case of spark gaps and isolation parts, they must be positioned outside the areas with a risk of explosion.

For outdoor technical installations with zones defined as 0 and 20 the atmospheric discharge protection requirements for zones 1, 2, 21 and 22 apply with some additions such as electrical equipment inside tanks containing flammable liquids must be suitable for this use and closed steel containers in which zones 0 and 20 exist must have a wall thickness of at least 5 mm. In the case of thin walls (thickness less than 5 mm) terminal devices for capturing atmospheric discharges must be installed.

4. CONCLUSIONS

Atmospheric discharges belong to the category of active ignition sources, being thus able to initiate explosive atmospheres generated by flammable/combustible substances mixed with air within the technical installations where these substances are processed, transported and stored.

In order to avoid the production of an explosion and/or fire as a result of the initiation of explosive atmospheres generated by flammable/combustible substances mixed with air through atmospheric discharges, technical installations where there are Ex areas must be protected against these sources of ignition.

To ensure a high level of security in the case of technical installations operating in environments with the risk of explosive atmospheres, it is very important to correctly apply the means and methods of protection against atmospheric discharges.

The correct application of means and methods of protection against atmospheric discharges of technical installations depends on the type of Ex., area which implies the classification of dangerous areas, generated by the presence of flammable/combustible substances, in zones (0, 1, 2 and 20, 21, 22).

Given the importance of the classification of dangerous areas, in Ex. areas, this must be carried out by competent persons who know the properties of flammable/combustible materials, processes, technical equipment as well as that information that allows establishing the type of Ex. area, and its extent from release source.

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LIMITING THE CONCENTRATION OF RADON IN BUILDINGS, A REQUIREMENT FOR PEOPLE'S HEALTH

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Abstract: *Radon is a radioactive gas from the decay of radium, the latter from the decay of uranium. It is present in certain soils and can be transported through porous media, especially through the phenomenon of diffusion. Thus, he can enter people's homes, public spaces or workplaces. RADON IS A RADIOACTIVE GAS THAT CAUSES CANCER. Radon is estimated to cause tens of thousands of lung cancer deaths each year. In fact, radon is the second leading cause of lung cancer in the world. Only smoking causes more lung cancer deaths. The paper presents some theoretical/practical and legislative aspects for the prevention of dangerous radon accumulations in buildings. A case study is also presented for a house where large amounts of radon were measured. The technical solution to reduce radon and the results of monitoring the concentration of radon radioactivity before and after the implementation of the technical solution are presented.*

Key words: *radon, radioactivity, lung cancer, accumulations in buildings, monitoring and prevention*

1. INTRODUCTION

Dubbed the "silent killer" in homes, radon is known to be the second leading cause of lung cancer, after smoking. Recently, however, according to a new study published online on January 31, 2024 in Neurology (the official journal of the American Academy of Neurology), exposure to even moderate levels of this radioactive gas—which pollutes both indoor air and underground jobs - is also associated with an increased risk of stroke [1].

In a study published in 2009, researchers from the World Health Organization (WHO) showed that radon is the main cause of 15% of lung cancer cases in the world. The International Agency for the Study of Cancer (IARC) classifies radon as the main carcinogenic environmental agent for the population [2].

Worldwide, 3–20 % of all lung cancer deaths are likely caused by indoor radon exposure. These values tend to be higher in countries reporting high radon concentrations, which can depend on the estimation method [3].

On the other hand, in recent years there has been a worrying increase in lung cancer cases in non-smokers, and the investigation of cases from various countries has shown that most of them are due to exposure to high concentrations of radon existing in homes, public facilities or places of the work. Therefore, studies were carried out

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and national and international strategies were developed for the prevention of diseases by monitoring the concentration of radon in buildings and taking appropriate measures to reduce it to non-dangerous values, where appropriate.

2. WHAT IS RADON? HEALTH RISK. LEGISLATION

Radon, a colorless and odorless gas, is emitted by the decay of radioactive materials found naturally in soil around the world.

Radon is a naturally occurring radioactive gas that has no taste, smell or color. It is produced by the radioactive decay of uranium and thorium, which are present in all soils and rocks in small amounts. There are a number of isotopes of radon, but the most important are radon-222 (derived from uranium-238) and radon-220 (derived from thorium-232). Radon-220, commonly known as thoron because of its parent radionuclide, provides much lower doses than radon-222 and will not be included in the analysis.

Because radon has a half-life of 3.82 days, it can diffuse into the soil before decaying. If it escapes from the ground into the outside air, it is rapidly diluted to low concentrations. However, indoor radon concentrations can reach high levels, usually not by diffusion of radon from the soil, but by an air flow that carries radon from the soil into buildings. This happens because the air pressure in the spaces in contact with the ground in most buildings is slightly lower than the air pressure below them. This causes a flow of air from the soil to be drawn into buildings, carrying radon with it.

Radon is soluble in water and under certain circumstances can be found in high concentrations in groundwater – for example, from wells or boreholes. If the water is used for domestic purposes, this is another route of exposure to radon.

Building materials can also be a source of indoor radon, although they are usually a much smaller source than soil.

When radon gas decays, it gives rise to isotopes of the solid elements lead, bismuth and polonium. These short-lived decay products are also radioactive and attach to natural aerosol particles in the atmosphere. Both unattached decay products and particle-attached decay products can be inhaled and then stick to the walls of the lungs and other parts of the respiratory system [4]. As these radon decay products undergo further decay, they emit alpha particles that irradiate the cells lining the walls of the respiratory system (fig. 1). It should be noted that the term "radon exposure" is used as shorthand for "exposure to radiation released by radon and its decay products."

Figure 1. Irradiation of the lungs with radon [2]

Radon can enter houses on earth through cracks in the floors, walls and foundation (fig. 2). When it accumulates indoors, radon can become a serious health problem and the phenomenon is increasing as modern building practices make homes more and more airtight.

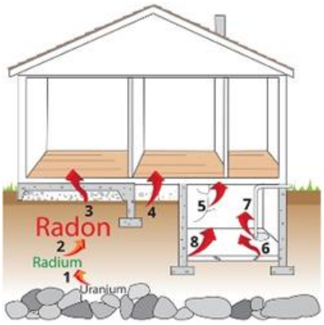

Figure 2. Radon ingress into houses. Source: UNIVERSITY OF NEVADA [5]

The danger that radon can pose is highly dependent on the concentration of uranium in the soil beneath the building.

The level of radon accumulated indoors depends on a number of factors that vary from the geological structure of the area to the type of air ventilation in the room or the nature of the work carried out in that space.

However, there are areas where the radon level is higher. Each European country has published a radon map showing areas with high radon concentrations.

The studies carried out so far have shown that Transylvania is the area most exposed to increases in radon in the air, but also large urban agglomerations: Bucureşti, Iaşi, Timisoara, Constanţa şi Braşov. Researchers from UBB (Babes-Bolyai University) made the first map of Radon in water and soil [6].

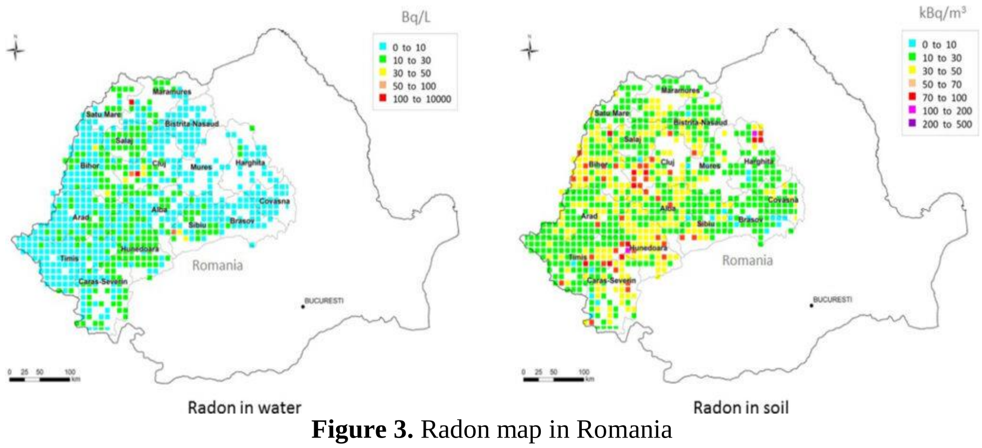

Figure 3. Radon map in Romania

Another important factor is the type of soil: more permeable soils allow more radon to penetrate, even if the level of the gas in the soil is low.

The way the house is built is also a risk factor. For example, in order to save energy, many modern houses have been built in such a way that they are almost airtight. Such non-ventilated buildings are prone to the accumulation of radon inside. An EPA (US Environmental Protection Agency) representative explained: "The more you try to make a house airtight, the higher the level of contamination."

The most recent research carried out in energy efficient homes indicates an increase in radon concentration by approximately 25% compared to homes that have not been thermally rehabilitated. [https://radoncontrol.ro/despre-radon/]. Thus, old houses in which air currents penetrate are probably less exposed to the harmful effects of radon. Controlled mechanical ventilation is a solution to prevent indoor radon accumulation but also to increase air quality. That's why rehabilitation and modernization works should also include ventilation with heat recovery, to ensure efficient ventilation with minimal heat loss.

3. RADON MONITORING. REDUCTION SOLUTIONS

3.1. Activity concentration reference limits

A number of physical quantities are used to describe the concentration of radon gas and its decay products.

A fundamental quantity is the activity, defined as the number of radioactive decays per second. The SI unit of activity is the becquerel (Bq), defined as one decay per second.

In the context of inhaled radon and its short-lived decay products it is usual to use activity concentration – the number of decays per second per cubic meter of air (Bq/m^3).

Bq/m^3 and pCi/L are different units of measurement for the radioactivity within a volume. Bq/m^3 is used globally, and pCi/L is almost exclusively used in the United States.

1 pCi/L = 37 Bq/m^3

Radon concentrations vary within very wide limits, from a few Bq/m^3 (a few radioactive disintegrations per second in a volume of one cubic meter) to several thousands or tens of thousands of Bq/m^3, being directly related to the geology of the area.

In 2013, European legislation proposed the unification of regulations regarding exposure to radon in the Member States _ EC Directive 2013/59 EURATOM. Thus, starting from 2018, Romania adopts the European recommendations and establishes a reference value of 300 Bq/m^3, above which it is mandatory to apply some measures to reduce the concentration of radon in the indoor air and control the efficiency of the remediation. In SUA 4 pCi/L is the recommended „action level”.

On the website of the US Environmental Protection Agency (epa.gov), in the section on health risk radon, it is stated that There's no "safe" level of radon exposure - 4pCi/L is the recommended "action level". Almost all radon problems can be easily fixed – levels can be reduced to 2-4pCi/L and in many homes even below 1pCi/L [7]

In Great Britain Action Level for radon of 200 Bq m–3. However, in a Radon and Public Health Report of the independent Advisory Group on Ionizing Radiation it is shown that Approximately 1100 deaths caused by radon through lung cancer occur every year in the UK, the majority resulting from exposure to concentrations well below 200 Bq/m^3, the current action level [8].

Table 1. Reference limits for radon in RO, UK si US

8,1 pC/l	300 Bq/m3	RO radon action level
5,4 pC/l	200 Bq/m3	UK radon action level
4 pCi/l	148 Bq/m3	US radon action level
2,7 pC/l	100 Bq/m3	radon safety level

HG 526/25.07.2018 for the approval of the National Radon Action Plan (PNAR) and the Order of the President of CNCAN no. 185/2019 regarding the Methodology for determining the concentration of radon in the air inside buildings and at workplaces provide for the obligation to measure and remedy the radon concentration in buildings, both residential and workplaces, being mandatory (Cf. Art. 23) measurements in all public buildings with a high degree of occupancy in Romania, such as public institutions, schools, kindergartens, hospitals, children's homes and elderly and other buildings with similar use [9].

In the European Code Against Cancer, in addition to recommendations on preventive lifestyle, diet, sport, smoking cessation, etc., stated in 12 points, there is also a mention on radon at number 9: "Find out if you are exposed to radiation with high levels of radon in your home. Take steps to reduce high radon levels".

In conclusion, preventing the risk of illness requires monitoring the radon concentration in buildings. Since the soil is the main source of radon inside buildings, it is recommended to monitor especially the rooms in direct contact with the soil. The international studies carried out in this field illustrated the fact that radon varies from one room to another as a result of the different way of use, the degree and type of ventilation, the type of floor, etc. As such, the best way to find out what we are exposed to is to take measurements. Also, we should not rely on the neighbors who have already taken measurements.

3.2. Methods and devices for measuring radon

Several methods and measuring devices are available for radon monitoring. In our country, GD 526/25.07.2018 was issued for the approval of the National Radon Action Plan (PNAR) and the CNCAN President's Order no. 185/2019 regarding the Methodology for determining the concentration of radon in the air inside buildings and at places of the work. This methodology is not applicable to private individuals who would like to check whether or not they have radon in their home.

In other states, test kits are available to the public from several sources. Free test kits are sometimes available from local or county health departments, or from state radon programs. The National Radon Program Services at Kansas State University has test kits available to purchase online or call 1-800-SOS-RADON (1-800-767-7236). Test kits are also available from some local or state American Lung Associations and some home improvement stores (fig. 4).

Figure 4. Short-term Test Kit & Long-term Test Kit
[https://sosradon.org/purchase-kits]

The costs are not high, and the results will be accessible on the site. [Short Term tests kits (2-4 days) are $17, which includes all costs. Just follow the instructions on the included Instruction Sheet and return the kit to the manufacturer (Alpha Energy in Texas) for analysis at no extra charge / Long term test kits (3-12 months) are $27, which includes all costs. Just follow the instructions on the package and return the kit to the manufacturer (RSSI in Illinois) for analysis at no extra charge.]

In our country, things are a little delayed. There are five Laboratories designated by CNCAN as laboratories for tests - Radon, and the prices are from 50 EUR upwards, which makes it impossible for the majority of the population to access them.

Figure 5. Radon test devices
Source: https://www.epa.gov/radon/how-do-i-get-radon-test-kit-are-they-free [7]

3.3. Solutions for reducing radon in homes

If, following the radon testing in the house, a high level of radiation results, immediate measures must be taken to reduce it. The good news is that the problem can be solved. There are several methods to reduce the level of radon in the home. Some techniques prevent radon from entering your home, while others reduce radon levels once it has entered. In general, methods that prevent the penetration of radon are recommended.

In homes that have a basement or slab foundation, radon is usually reduced by one of four types of soil suction: subsoil suction, drain-tile suction, sump-hole suction, or block-wall suction.

Active subslab suction (fig. 6)— also called subslab depressurization — is the most common and usually the most reliable method of radon reduction. One or more suction pipes are inserted through the floor slab into the crushed rock or soil below. They can also be inserted under the concrete slab in the walls of the house in contact with the ground. The number and location of suction ducts that are required depends on how easily air can move in the crushed rock or soil beneath the slab and the strength of the radon source. Often only a single suction point is required.

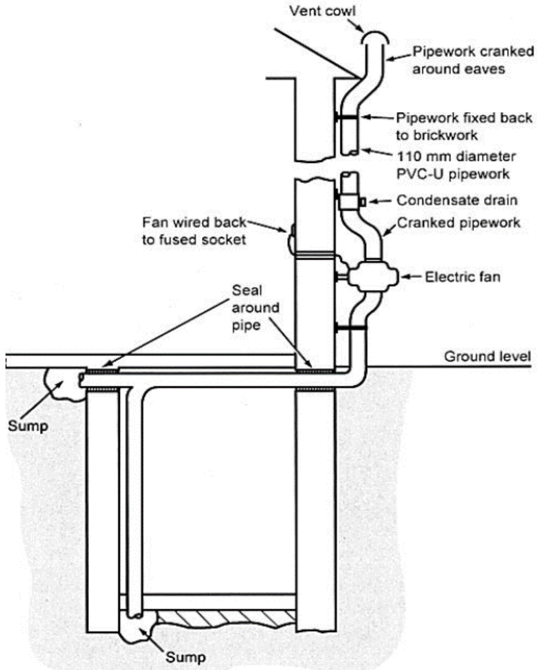

Figure 6. Active subslab suction — also called subslab depressurization

A radon vent fan connected to the intake pipes draws radon gas from under the house and releases it to the outside air, simultaneously creating a negative pressure or vacuum under the slab.

Passive subslab suction is the same as active subslab suction, except that it relies on natural pressure differences and air currents instead of a fan to extract radon from under the house. Passive subslab suction is usually associated with radon-resistant features installed in newly constructed homes. Passive subslab suction is generally not as effective at reducing high radon levels as active subslab suction.

Some homes have drain tiles or perforated pipe to direct water away from the home's foundation. Vacuuming these tiles or pipes is often effective in reducing radon levels.

A variant of suction is suction through the sump hole. Often, when a home with a basement has a sump pump to remove unwanted water, the tank can be covered so that it can continue to drain and serve as a location for a radon suction pipe.

Block wall suction can be used in basement homes with hollow block foundation walls. This method removes radon and depressurizes the block wall, similar to sub-slab vacuuming. This method is often used in combination with subplate suction.

In some cases, radon levels can be lowered by passive or active ventilation of the access space, with the help of a fan. Access space ventilation can reduce indoor radon levels both by reducing the house's suction on the ground and by diluting the radon below the house. Passive ventilation in an access space is achieved by opening vents or installing additional vents. Active ventilation uses a fan to blow air through the access space instead of relying on natural air circulation. In colder climates, for either passive or active crawlspace ventilation, water pipes, sewer lines, and crawlspace appliances may need to be insulated against the cold. These ventilation options could lead to higher energy costs for the home.

Other radon reduction techniques that can be used in any type of home include: sealing, pressurizing the house or room, heat recovery ventilation, and natural ventilation.

Sealing cracks and other openings in the foundation is a basic part of most radon reduction approaches. Crack sealing limits the flow of radon into your home, making other radon reduction techniques more effective and cost-effective. It also reduces air conditioning loss. It is not recommend using caulking alone to reduce radon because caulking by itself has not been shown to significantly or consistently lower radon levels. It is difficult to identify and permanently seal the places where radon enters. The normal layout of your home opens up new entryways and reopens old ones.

Home or room pressurization uses a fan to blow air into the basement or upstairs living area or outdoors. It tries to create enough pressure at the lowest level indoors—in a basement, for example—to prevent radon from entering the home. The effectiveness of this technique is limited by the construction of the house, the climate, other appliances in the house and the lifestyle of the occupants. To maintain sufficient pressure to keep radon out, doors and windows on the lowest level should not be left open except for normal entry and exit.

This approach generally results in more outside air being brought into the home, which can cause moisture ingress and energy penalties. Consequently, this technique should only be considered after other, more common techniques have not sufficiently reduced radon.

4. CASE STUDY (RADON MONITORING, CONSTRUCTIVE SOLUTIONS, IMPLEMENTATION/MONITORING)

Since the presence of radon was suspected in a house in Valea Jiului, radon concentrations were monitored for a period of three weeks with the house closed, uninhabited.

Three Airthings Wave Plus radon monitoring devices were used. Airthings Wave Plus (fig. 7) is an app-enabled indoor air monitor that measures 6 aspects of air quality, including radon, carbon dioxide (CO2), and more. The readings are synchronized live with the Airthings app on your mobile phone via Bluetooth.

Figure 7. Airthings Wave Plus

The devices were installed in the cellar, in the living room on the ground floor and in the attic

The results of the measurements were extremely worrying, reaching 20,000 Bq/m^3 in the cellars, which constitutes a great danger for the health of the tenants (the norms indicate 300 Bqr/m^3 radon action level)

Figure 8. Graph of radon evolution in cellars

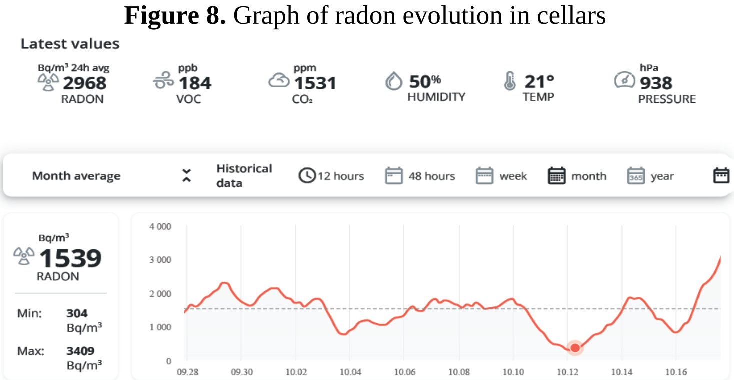

Figure 9. Graph of radon evolution in room 2/ground floor

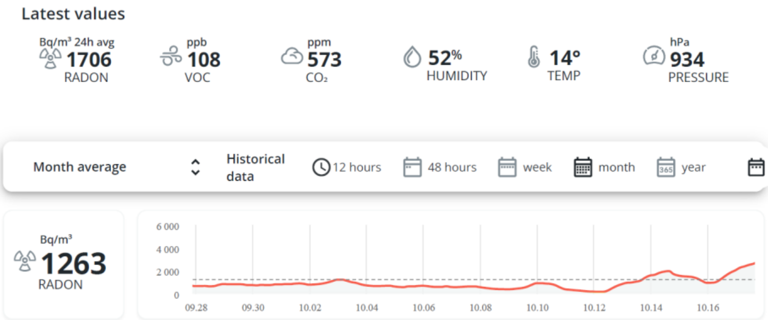

Figure 10. Graph of radon evolution in room 1/attic

Table 2. Radon measurements

Place	**Medium value [Bq/m^3]**	**Max. Value [Bq/m^3]**	**Min. Value [Bq/m^3]**
Basement	14.000	20.000	1.303
room 2 / ground floor	1.539	3.409	304
Room 1/attic	1.263		

Monitoring period was 24.09.2022 ÷14.10.2022.

NOTE: The minimum values were measured on the days when the doors to the house were opened.

There followed a short period of documentation examining the radon reduction solutions, the following bibliographic sources being particularly useful:

- Consumer's Guide to Radon Reduction How to Fix Your Home EPA 402/K-10/005 | March 2013 | www.epa.gov/radon

- Public Health England Reducing Radon. Underground rooms -cellars and basement- PHE publications gateway number: 2015110 Published: June 2015 https://www.ukradon.org/cms/assets/gfx/content/

- The issue of the presence of radon in buildings in Romania by. Bercea Mihai sa https://aaecr.ro/wp-content/uploads/2019/06/01-Radon-articol-BerceaECM_var2.pdf

A series of measurements followed with the naturally ventilated house, then, in the first stage, a forced ventilation system was created in the cellar with the help of a fan. Values have decreased, but not significantly.

Analyzing the construction of the cellar, it was noticed that there is a spout in the floor that drains the water used to wash the cellar, directly into the ground. After removing the drain grid, a large hollow was found under the floorboard. This sump – hole was actually a perfect radon trap/collector (fig. 11).

Figure 11. The sump–hole as radon trap/collector

Therefore, a radon capture and evacuation system was created from under the basement slab through the existing drain with plastic pipes used for water sewer pipes with a diameter of 110 mm. Initially, the system was tested without a fan (Passive suction under the plate) without good results and then an axial fan was mounted outside (System with active suction under the plate) (fig. 12).

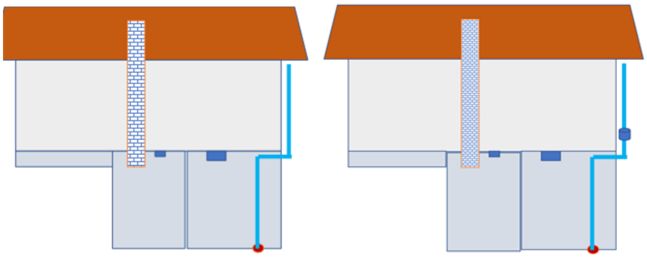

Figure 12. System with passive underplate suction (left) / System with active underplate suction (right)

Figure 13. The elements of the underplate active suction system

It was found that the implemented solution solves the radon problem very well. As long as the fan is working, the measured values are below 100 Bq/m^3, which is safe for health. If the fan stops, immediately the radon rises to over 1000 Bq/m^3- (fig. 14).

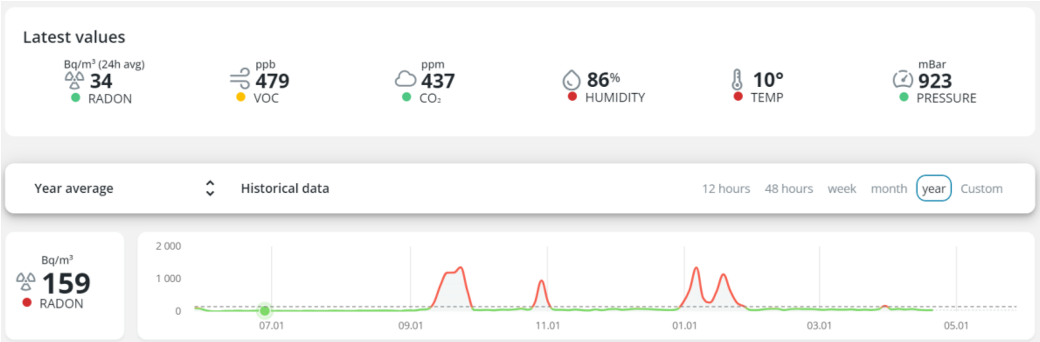

Figure 14. The variation of radon in the cellar between 01.06.2023 ÷ 20.04.2024 (fan in operation with four experimental stops - red areas)

Since the radon level increases in the absence of electricity, the experiments will continue under the conditions of sealing the cellar at the entrance of the pipes through the walls and detecting/sealing the cracks. There will also be other ventilation holes at the ceiling level and the measurements will be repeated with and without the fan in operation.

5. CONCLUSIONS

Radon, a colorless and odorless gas, is emitted by the decay of radioactive materials found naturally in soil around the world.

Radon can enter earthen houses through cracks in floors, walls and foundations. When it accumulates indoors, radon can become a serious health problem as it is known that RADON is the second cause of lung cancer in the world, after smoking.

If, following the radon testing in the house, a high level of radiation results, immediate measures must be taken to reduce it. There are several methods to reduce the level of radon in the home. Some techniques prevent radon from entering your home, while others reduce radon levels once it has entered.

In the European Code Against Cancer, in addition to recommendations on preventive lifestyle, diet, sport, smoking cessation, etc., stated in 12 points, there is also a mention on radon at number 9: “Find out if you are exposed to radiation with high levels of radon in your home. Take steps to reduce high radon levels”.

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THE ENVIRONMENTAL IMPACT OF NATURAL GAS PIPELINE ACCIDENTS

Ladislau RADERMACHER[1], Florin FAUR[2], Diana MARCHIȘ[3]

Abstract: *Natural gas pipeline accidents have severe environmental consequences, affecting air, soil, water, and biodiversity. Methane emissions, a potent greenhouse gas, contribute to climate change, while soil and water contamination harms local flora and fauna. Resulting fires can destroy natural habitats. Common causes of these accidents include pipeline corrosion, excavation activities, and human errors or technical failures. Effective prevention and management require proactive monitoring, modern leak detection technologies, education and training of personnel, and well-developed emergency response plans. By adopting preventive measures and ensuring swift responses, the negative impact of accidents can be mitigated, thereby protecting the environment.*

Key words: *accidents, environment, impact, natural gas, pipeline*

1 INTRODUCTION

Natural gas pipeline accidents can significantly impact the environment, affecting air, soil, and water quality, as well as biodiversity and public health. This article explores the various ways these accidents influence the environment and proposes preventive and mitigation measures.

The natural gas industry in Romania has experienced rapid growth in recent decades, driven by favorable energy policies and advances in extraction technology. One of the most visible and controversial aspects of this expansion is the construction of inter-European gas transport pipelines. The purpose of this process is to assess the necessity of new pipelines in relation to the social and environmental risks associated with each project.

Today, the transfer of gas from production sources to consumption sites represents one of the most important issues for governments. Although there are various methods of transferring fossil energy sources, such as maritime or rail transport, terrestrial methods are the most significant due to the advantages offered by main pipelines and the lower economic risk [1].

Gas transport pipelines are essential components of this system and are used to transport large volumes of methane over long distances from producers and processing plants to regional and global distribution centers. These pipelines include a large-

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diameter main pipeline and smaller adjacent pipelines that transport gas to and from the main pipeline.

However, the construction and operation of gas pipelines involve a series of risks [2-7]. These are not limited to the area of execution or operation; they transport hazardous and explosive materials at high pressure and are vulnerable to natural or human-induced risks. The social and environmental risks associated with major gas pipelines are well-documented, but environmental impact assessment documents are often lengthy and complex [8-12]. They present the risks in detailed ways, making it difficult for decision-makers and the public to understand and present the dynamics and variability of the risks.

Thus, while the construction of new gas pipelines can bring economic and energy benefits, it is essential to consider the associated social and environmental risks. A careful balance is necessary between the need for energy infrastructure and the protection of the environment and local communities.

2 NATURAL GAS PIPELINE FAILURES

Releases of products transported through pipelines can have environmental impacts and can lead to injuries, fatalities, and property damage. The risk associated with pipelines varies depending on several factors, such as the product being transported, the size and operating pressure of the pipeline, and the proximity of populations and natural resources.

For natural gas pipelines, the highest risk is associated with fires or explosions caused by the ignition of natural gas, which can result in significant property damage and injuries or fatalities. Additionally, the release of natural gas, primarily methane—a potent greenhouse gas—contributes to climate change [12-17].

While aging infrastructure is a concern, age alone does not fully indicate the risk of pipeline failure. Factors such as the types of materials used, installation techniques, welding methods, the implementation of corrosion prevention measures, and the maintenance practices all influence the likelihood of a failure. Although each of these factors can contribute to the risk of a pipeline failure, a well-managed system by the operator can mitigate the impact of aging and construction materials.

There are two types of pipeline incidents: methane gas leaks and ruptures. A methane gas leak is a slow release, whereas a rupture is a sudden breach in the pipeline (Figure 1). Generally, leaks are more common but cause less damage, while ruptures are relatively rare but can have catastrophic consequences.

Figure 1. Severe gas leak (image generated with ChatGPT4o)

A pipeline failure is defined as an incident related to the gas transport network that causes a sudden change in the technical state of the pipeline and poses a danger to human health and life, as well as to the environment. The causes of pipeline failures can be classified into three main categories: corrosion damage, mechanical damage, and third-party interference or errors. Additionally, another criterion for classifying pipeline failures is the division into intra-systemic and extra-systemic failures.

The first category includes damage caused by welding defects, material defects, or defects in pipeline fittings. These issues primarily arise due to irregularities during the construction and repair of the pipeline. Corrosion damage, which can affect both the interior and exterior surfaces of steel pipeline walls, also falls into this category. Corrosion can manifest in various forms, such as stress corrosion, electrochemical corrosion, or chemical corrosion. It can appear as pitting corrosion (localized corrosion) or as uniform corrosion, characterized by the consistent and even loss of metal from the pipeline surface. These processes are often triggered by scratches, deterioration, or micro-cracks in the gas pipeline's surface structure. Intrasystemic causes of gas pipeline failures also include damage related to the instability of the pipeline's placement in the ground.

The group of extrasystemic threats includes unintentional or intentional human activities, such as acts of vandalism, terrorist actions, thefts, and accidental damage caused during engineering or construction works. This group of pipeline damage causes also includes hazards related to the impact of natural forces, such as ground displacement due to earthquakes, rock mass movement, or ground subsidence caused by floods [18- 21].

Statistics on the main causes of pipeline failures, including pipeline corrosion, external factors, human errors, irregularities in installation and assembly processes, and defects occurring during the manufacturing process, are presented in Figure 2. All incidents reported by cause for the period 2008-2018 in Hunedoara County [22] show results similar to other sources [18, 23- 25].

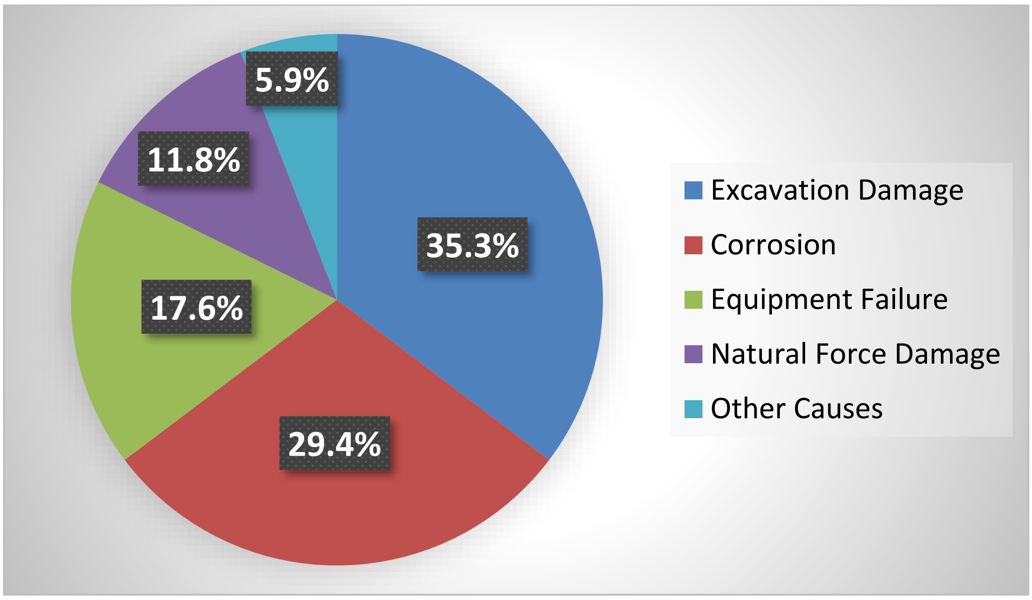

Figure 2. Incidents reported by cause in Hunedoara County (source: [22])

3 IMPACT ON ATMOSPHERE

Natural gas leaks can lead to the release of methane (CH_4) into the atmosphere, a potent greenhouse gas. Methane emissions significantly contribute to global warming and climate change. Additionally, natural gas can contain volatile organic compounds (VOCs) and other pollutants that can deteriorate air quality and cause respiratory health problems in humans.

Methane (CH_4) is one of the six greenhouse gases (GHGs) mitigated under the Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC). The other gases are carbon dioxide (CO_2), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). The atmospheric concentration and sources of CH_4 are not well understood or quantified and are highly disputed [8, 9]. Furthermore, official inventories underestimate actual CH_4 emissions [10], despite a global increasing trend of CH_4 [11].

The issue of methane emissions due to accidents in transportation or distribution pipelines and during the extraction and processing is significant, even though the lifetime of CH_4 once released into the atmosphere is approximately 12 years [12]. Methane is 25 times more potent than CO_2 in trapping atmospheric heat over a 100-year period (IPCC) [13]. Reducing methane emissions is crucial for mitigating global warming, contributing to limiting the increase in global average temperature to no more than 2°C (US EPA) [14].

Methane emissions from global oil and natural gas systems are expected to increase by 26% by 2030 (US EPA) [14]. Transportation systems are a significant source of anthropogenic CH_4 emissions, particularly because pipelines are old, susceptible to leaks due to corrosion and abrasion, and are not frequently inspected. This makes them one of the largest sources of CH_4 emissions in the gas industry [15]. Some studies have identified natural gas transportation systems as one of the main sources of CH_4 emissions [9, 18, 17].

For example, according to calculations by the Federal Environment Agency (UBA) [26-28], leaks from the Nord Stream 1 and 2 pipelines lead to emissions of approximately 7.5 million tonnes of CO_2 equivalent. This corresponds to about one percent of Germany's total annual emissions. The calculation is based on estimated information about the filling state and volume of the two pipelines. Since there was no insulation system on the pipelines, most likely, the entire gas mixture (mainly methane) dissipated into the water, and subsequently into the atmosphere. The suspected sabotage of both Nord Stream pipelines could represent one of the most severe industrial methane release incidents in history [29, 30].

4 IMPACT ON SOIL AND WATER

Accidents involving natural gas pipelines can have particularly severe consequences on soil and water, causing contamination that affects the environment in the long term. This section describes how these accidents influence soil and water, the consequences on ecosystems and human health, and the necessary measures for preventing and managing these impacts.

4.1 Soil contamination and effects on vegetation

Natural gas leaks can introduce hazardous chemicals into the soil (Figure 3). These substances may originate from additives used in the extraction and transportation process of natural gas. Soil contamination affects its structure and fertility in the following ways:

1. Nutrient degradation - toxic chemicals can interfere with essential nutrients in the soil, affecting plants' ability to absorb these nutrients. This can lead to reduced agricultural productivity and impact local vegetation;
2. Alteration of soil structure - contaminants can change the physical structure of the soil, affecting its ability to retain water and air. This can result in soil compaction and reduce its capacity to support plant life;
3. Toxicity to microorganisms - soil microorganisms, which play a crucial role in decomposing organic matter and cycling nutrients, can be negatively affected by contaminants. This can disrupt the ecological balance and reduce soil fertility.

Figure 3. Effects of gas leaks on soil and vegetation (image generated with ChatGPT4o)

4.2 Water contamination and effects on aquatic organisms

Accidents involving natural gas pipelines can affect both surface water and groundwater. Contamination of water sources can have devastating effects on aquatic ecosystems and human health (Figure 4):

1. Infiltration of toxic substances - gas leaks can transport toxic substances into groundwater, which can contaminate wells and other drinking water sources. This represents a major health risk, potentially causing severe diseases and infections;
2. Eutrophication - in some cases, leaks may contain excess nutrients, such as nitrogen and phosphorus, which can lead to the eutrophication of water bodies. Eutrophication causes excessive algae growth, which depletes oxygen in the water, affecting aquatic life;
3. Destruction of aquatic habitats - chemical contaminants can destroy aquatic habitats, impacting flora and fauna. Fish species, amphibians, and other aquatic organisms may experience high mortality rates or face the loss of critical habitats needed for reproduction and survival;
4. Bioaccumulation - toxic substances can enter the food chain through bioaccumulation, affecting various species and ultimately reaching humans through the consumption of contaminated fish and other aquatic organisms.

Figure 4. Effects of gas leaks on surface water and aquatic life (image generated with ChatGPT4o)

5 IMPACT OF EXPLOSIONS

In extreme cases, explosions of natural gas pipelines can have a devastating impact on the environment:

1. Physical destruction of ecosystems - explosions can cause the physical destruction of adjacent areas, including vegetation and animal habitats. This can lead to a loss of biodiversity and the disruption of local ecosystems. Apart from the explosion itself, depending on the location of the gas pipelines, these events can be followed by massive vegetation fires, extending the catastrophic effect on ecosystems but also on possible infrastructure, buildings, etc.

2. Soil erosion - Explosions can destabilize soil structure, leading to accelerated erosion. Eroded soil can be transported into water bodies, causing sedimentation and affecting water quality and aquatic habitats.

5.1 Example 1

A gas pipeline rupture in Ghislenghien, Belgium in 2004 (Figure 5), caused by construction work, led to a massive explosion, killing 24 people and injuring 120 [31].

Figure 5. The Ghislenghien explosion (source: [32, 33])

The explosion resulted in severe environmental contamination, including the release of toxic substances into the air and soil, and destroyed nearby buildings. Numerous victims suffered severe burns and other injuries due to the intense flames and powerful shockwave [32, 33].

5.2 Example 2

In the early hours of September 21, 2023, at around 01:15 AM, a major technical incident involving fire occurred on the Dn800 natural gas transmission pipeline between Șendreni and Onești, near the village of Călimănești in Vrancea

County (Figure 6). The incident took place at kilometer 93+328 from SCV Șendreni and kilometer 52+174 from NT Onești, during construction work on the A7 Moldova Highway (Focșani-Bacău), as reported by Transgaz in a press release [34-37].

Figure 6. The accident from Călimănești (source: [38])

- Cause and immediate effects - the explosion was triggered during construction activities, indicating a possible breach of the pipeline by construction equipment. The immediate effect was a significant fire, which posed a substantial risk to both workers and nearby residents. Emergency response teams were likely dispatched to control the fire and mitigate further damage.
- Environmental impact - the release of natural gas into the atmosphere during the explosion would have contributed to air pollution, including the emission of methane, a potent greenhouse gas. The fire also likely caused localized air quality issues, with the potential for toxic fumes affecting nearby areas. Soil and water contamination could also be a concern, depending on the extent of the gas release and firefighting efforts.
- Impact on local infrastructure - the incident caused disruption to the construction schedule of the A7 Moldova Highway, a key infrastructure project intended to improve regional connectivity. Damage to the pipeline required immediate attention to restore gas transmission and ensure the safety of the area. Local infrastructure, including roads and possibly residential buildings, may have been affected by the blast and subsequent fire.
- Safety and regulatory implications - this incident emphasizes the need for stringent safety measures and coordination between utility operators and construction companies. Regulatory bodies may need to review and enhance guidelines to prevent

such occurrences, ensuring that construction activities do not compromise the integrity of critical infrastructure.

- Response and mitigation - Transgaz, as the operator of the pipeline, would need to conduct a thorough investigation to determine the exact cause of the incident and implement measures to prevent future occurrences. This might include enhanced monitoring of construction activities near pipelines, more robust safety protocols, and increased communication between all parties involved in such projects.

The pipeline explosion in Vrancea County (in which 4 people were killed and 5 others severely injured [34-38]) serves as a critical reminder of the complexities involved in managing infrastructure projects that intersect with essential service utilities. It highlights the need for comprehensive safety measures, effective regulatory oversight, and coordinated efforts between construction companies and utility operators to ensure public safety and environmental protection.

6 MITIGATION STRATEGIES AND SAFETY MEASURES FOR NATURAL GAS PIPELINES

To ensure the integrity and safety of natural gas pipelines, it is essential for owners, supervisors, and technicians to implement strict measures. Any deficiencies or non-compliance with communication, maintenance, monitoring, or safety standards can have serious consequences. To minimize the risk of pipeline ruptures, the following strategies are recommended:

Adoption of advanced monitoring technologies: Implementing advanced monitoring technologies, such as leak detection systems and state-of-the-art sensors, can significantly enhance the ability to detect potential problems before they become critical. Continuous monitoring allows real-time assessment of pipeline conditions, giving operators the opportunity to respond promptly to emerging threats and prevent ruptures.

Comprehensive inspection and maintenance program: Implementing a thorough inspection and maintenance program is vital for maintaining the integrity of natural gas pipelines. Regular inspections, utilizing techniques such as "smart pigs" (pipeline inspection devices), and routine maintenance activities can identify and address issues related to corrosion, material defects, and other potential deficiencies, thereby reducing the risk of rupture.

Public awareness and education: Promoting public awareness regarding the location of natural gas pipelines and the associated risks is essential for preventing external interferences. Educating communities, construction teams, and emergency response personnel about the importance of reporting suspicious activities near pipelines and adhering to safety protocols helps minimize the risk of ruptures caused by human intervention.

Development and testing of emergency response plans: Developing and periodically testing emergency response plans are crucial for minimizing the impact of natural gas pipeline ruptures. Collaboration between local authorities, emergency services, and pipeline operators is essential to ensure an effective and coordinated response in the event of a rupture, focusing on evacuation procedures, isolation measures, and medical assistance.

Implementing these mitigation strategies and safety measures can ensure safer and more reliable operation of natural gas transportation infrastructure, reducing risks to communities and the environment.

7 CONCLUSIONS

The impact of natural gas pipeline accidents on the environment is profound, encompassing air, soil, and water contamination, as well as the potential for catastrophic explosions. Methane emissions from leaks are a significant concern due to their contribution to global warming and climate change. Contaminants from natural gas can degrade air quality, affect human respiratory health, and disrupt aquatic and terrestrial ecosystems.

In the realm of water contamination, both surface and groundwater can be severely impacted by toxic substances and nutrients leading to eutrophication, habitat destruction, and bioaccumulation of harmful chemicals. Explosions can cause immediate and extensive physical damage to ecosystems, leading to soil erosion and long-term environmental degradation.

To mitigate these risks, several strategies are essential. The adoption of advanced monitoring technologies can detect potential issues early, while comprehensive inspection and maintenance programs can address existing problems. Public awareness campaigns can prevent accidental damage by informing communities about pipeline locations and associated risks. Moreover, developing and regularly testing emergency response plans ensures readiness in case of pipeline failures.

In summary, while natural gas pipelines are critical for energy infrastructure, their associated environmental risks necessitate rigorous safety measures and proactive management. Balancing the benefits of natural gas transportation with the need to protect the environment and public health is crucial for sustainable development. Implementing advanced technologies, comprehensive maintenance, public education, and robust emergency response strategies can significantly enhance the safety and reliability of natural gas pipelines.

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CREATION OF EXPLOSIVE AIR-HYDROGEN MIXTURES FOR CONTROLLED PHYSICAL EXPERIMENTS

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Abstract: *This paper presents the use of an automatic system for the preparation of gas mixtures in order to obtain a homogeneous hydrogen-air mixture, at concentrations within the explosion limits for flammable gases, from 4 % volume fractions (lower flammability limit) to 75 % volume fractions (upper flammability limit) and with a precision suitable for laboratory applications. The system is managed by a software specially designed by the author, which controls the mixing of two volumetric flows, stored and circulated at atmospheric pressure with the help of two cylindrical injectors, subsequently driven by step-by-step electric motors. The system is tested by preparing the hydrogen-air mixture at the desired concentrations and subsequently, the results are measured using a hydrogen sensor to confirm them.*

Keywords: *hydrogen explosion, CFD calculations, clean energy, risk assessment*

1 INTRODUCTION

Hydrogen, that is highly flammable and versatile gas, is increasingly used in various industrial applications and scientific research. Accurate measurement and control of hydrogen concentrations in gas mixtures are essential for ensuring safety and optimizing processes. This research paper outlines the process of creating hydrogen gas mixtures and validating their concentrations using two different detection systems: a custom-built Arduino-based hydrogen sensor and a professional multi-gas detector. The process to obtain precise hydrogen gas mixtures [1] requires some basic materials such as a gas mixture system, which typically includes the following components:

- Gas cylinders: containing technological hydrogen and a diluent gas such as nitrogen or air.
- Flow controllers: regulating the flow rates of hydrogen and the diluent gas to achieve the desired mixture concentration.
- Mixing chamber: ensuring thorough mixing of the gases before sampling.

In order to prepare a hydrogen mixture with a specific hydrogen concentration, the flow controllers are adjusted according to the required ratios. For example, to achieve a 5% hydrogen mixture in air, the flow rates are set so that hydrogen constitutes 5% of the total gas flow of 10 dm^3. After the use of an automated system

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for gas mixtures to obtain desired hydrogen concentration, to validate the concentration of the prepared hydrogen mixture, two different detection systems are used.

1.1 Hydrogen sensor for Arduino board

The first system used to validate hydrogen concentration is an Arduino based hydrogen sensor system, this system comprises an MQ-8 hydrogen sensor connected to an Arduino board, the sensor detects hydrogen levels through changes in resistance, which are then converted to a voltage output a processed by the Arduino board. In short terms, the sensor is calibrated with known hydrogen concentration, then a sample of the gas mixture is provided to the sensor and it`s recorded his response, and for the final step, the hydrogen concentration is calculated based on the calibration curve set in the calibration process.

1.2 Multi gas detector

The second system used to validate hydrogen concentration is a professional multi-gas detector equipped with sensors for various applications with gases, that provides accurate and reliable measurements. Detectors like the one used are often pre-calibrated and even has an automatic calibration procedure. The procedure is similar with the first system used, so a calibration of the detector according to the manufacturer`s instructions is required, then the detector is exposed to the prepared hydrogen gas mixture and records of hydrogen concentrations are displayed by the detector on a digital screen.

Comparing the hydrogen concentration readings from the Arduino based sensor and the professional multi gas detector, the accuracy and reliability of the gas mixing system can be validated. This comparison helps in identifying any discrepancies and making necessary adjustments to the calibration factor from the Arduino gas system and the professional detector serves as a standard due to its higher precision and accuracy. Creating and validating hydrogen gas mixture involve meticulous preparation and calibration. The combination of this cost-effective Arduino hydrogen sensor system and a professional multi gas detector, allows for through validation of hydrogen concentration, ensuring both safety and process efficiency. The technique used in this paper is crucial in industrial applications, laboratory experiments, where precise hydrogen measurements are a must.

1.3 The role of hydrogen as a future fuel

Being the most abundant element in the universe, hydrogen is found as part of the molecules of water, methane [2], and organic material, fresh or fossilized. Hydrogen production involves extracting and isolating hydrogen in the form of independent molecules, at the level of purity required for a given application. Thus, in the case of fossil fuels, the transformation of natural gas into hydrogen is relatively easy and that of oil is a little bit more elaborate, while transformation of coal requires an initial step of high temperature gasification. For energy already transformed to electricity, electrolysis is presently the most common process for hydrogen production.

Photo induced or direct thermal decomposition of water at high temperatures may be considered, while more complex, multi-steps schemas are required at lower temperatures, such as those offered by steam from nuclear reactors. Properties of hydrogen are listed in Table 1.

Table 1. Properties of hydrogen

Properties	**Values**	**Units**
Autoignition temperature	500	°C
Boiling point (1 atmosphere)	-252.9	°C
Density (at 20°C and 1 atmosphere)	0.08375	kg/m^3
Diffusion coefficient in air	0.610	cm^2/s
Enthalpy	3858.1	kJ/kg
Flame temperature in air	2045	°C
Flammable range in air	4.0 – 75.0	% vol.
Ignition energy in air	2×10^{-5}	J
Molecular weight	2.02	g/mole

1.4 Combustion properties for fuel – air mixtures

The gas explosion consequences will depend on the type of fuel and oxidizer and the fuel and oxidizer concentration. Through years of research, essential characteristic properties for characterizing the reactivity and damage potential of various combustible substances have been established. A premixed fuel – air mixture will only burn as long as the fuel concentration is between the lower flammability limit and the upper flammability limit, a visual representation of this flammability limits is listed in Figure 1.

The flammability limits are experimentally determined data, the flammability limits [3] in air depend on initial temperature and pressure. Standard conditions are 25° Celsius and 1 atmosphere.

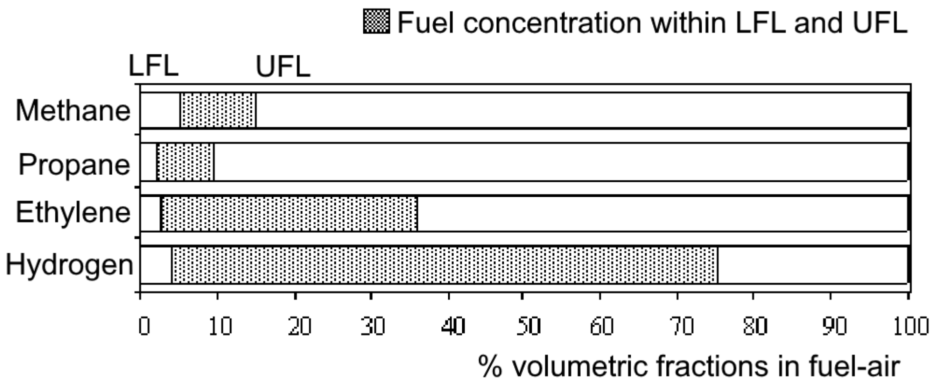


Figure 1. Flammable range for some fuel-air mixtures at 25° Celsius and 1 atmosphere

The wide flammable range of hydrogen, means that is easy to get a flammable cloud [4] of hydrogen in air. For propane and methane, the flammable range is much narrower, and an ignition source may sit and wait until the cloud can be ignite and explode. The flammability limits for fuel mixtures are calculated with the formula of Le Chatelier:

$$LFL_{mixture} = \frac{100}{\frac{C_1}{LFL_1} + \frac{C_2}{LFL_2} + \cdots + \frac{C_i}{LFL_i}} \tag{1}$$

where C_1, C_2 ,..., C_i [%vol.] is the proportion of each gas in the fuel mixtures without air. In the case of hydrogen, the formula does not work properly and the same for unsaturated hydrocarbons. It is also only valid if the components are chemically similar.

Stoichiometric compositions [5] are another property of fuel-air mixtures and are defined as the composition where the amounts of fuel and oxygen (air) are in balance so that there is no excess of fuel or oxygen after the chemical reaction has been complete. Various fuels come in various concentration which can be found in Table 2.

Table 2. Stoichiometric concentration for various fuels in air

	Hydrogen	**Ethylene**	**Propane**	**Methane**
% fuel (volumetric)	30	6.5	4.0	9.5
(g/m^3)	26.9	81.7	79.1	67.8

Another important property of fuel-air mixtures is the minimum ignition energy, that is a measure of required energy for a localized ignition source, like a spark, to successfully ignite a fuel-oxidizer mixture, so the ignition energy is strictly depended on the fuel concentration. For most combustible fuels the minimum energy is between 0.1 and 0.3 mJ in normal ambient air. Regarding hydrogen, acetylene and carbon disulphide have one order of magnitude lower minimum ignition energy.

2 UNDERSTANDING THE HYDROGEN CONCENTRATION IN A GAS MIXTURE

Correlating the concentration of hydrogen in a mixture using for example a methane detector requires an understanding of the working principle of this detector and the difference in sensor behavior to hydrogen and methane. In the following we go through several important stages and considerations. Methane detectors are usually equipped with catalytic combustion sensors or infrared sensors. These catalytic sensors detect flammable gases by oxidizing the gas on a heated filament, which changes the resistance of the filament. Infrared sensors detect gases [6] by the absorption of infrared light at certain wavelengths by the gas. Most methane sensors are also sensitive to other flammable gases, including hydrogen. However, the sensor response can vary significantly between different gases. This is due to differences in oxidation energy and in the infrared absorption spectrum.

2.1. Hydrogen sensor calibration

In order to correlate the hydrogen concentration with the response of the methane detector, a specific hydrogen calibration must be performed. This process involves exposing the sensor to known concentrations of hydrogen and recording the sensor response for each concentration. Thus, a relationship can be established:

$$\text{Sensor response} = \text{f}(\text{concentration } H_2) \tag{2}$$

2.2 Calibration curve

A calibration curve can be created that correlates the sensor response with the hydrogen concentration. This curve can be linear or non-linear, depending on the type of sensor and its specifications.

$$\text{Concentration } H_2 = a * (\text{sensor response}) + b \tag{3}$$

Were *a* and *b* being constants determined by calibration.

2.3 Conversion factor

If it is not possible to calibrate the hydrogen sensor directly, conversion factors can be used based on the relative sensitivity of the hydrogen sensor to methane. These can be provided by the sensor manufacturer or determined experimentally.

$$\text{Concentration } H_2(\%) = \text{Conversion factor x } (CH_4 \text{ concentration}) \tag{4}$$

2.4 Experimental determinations

This determination below shows a clear and detailed process for calibrating a methane detector so that it can be used to measure hydrogen concentration. It is important to perform this calibration carefully and validate the obtained relationship to ensure the accuracy of the measurements. Table 3 contains the value obtained from sensor response in hydrogen mixture.

Table 3. Voltage readings from sensor in hydrogen mixture

Hydrogen concentration	Response measurements
1% H_2 in air	1% H_2: 0.8 V
2% H_2 in air	2% H_2: 1.6 V
3% H_2 in air	3% H_2: 2.4 V
4% H_2 in air	4% H_2: 3.2 V
5% H_2 in air	5% H_2: 4.0 V

$$\text{Concentration } H_2(\%) = \frac{\text{Response sensor (V)}}{0.8} \tag{5}$$

Based on the relation (5), if we measure 2.5 volts reading from the sensor, we can validate the output concentration as follows:

$$\text{Concentration } H_2(\%) = \frac{2.5\ (V)}{0.8} = 3.125\ \%\ \text{vol.}$$

Application results are listed in Table 4.

Table 4. Mathematical determination of H_2 concentration

Sensor response (V)	Calculation of H_2 (%)	Determined H_2 (%)
2.0 V	2.0 / 0.8	2.5 %
2.5 V	2.5 / 0.8	3.125 %

3 HYDROGEN-AIR MIXTURE WITH COMPUTERIZED STAND

In this chapter, a patented automated stand is used in order to obtain desired hydrogen concentration. The first syringe pump from the stand, will store an amount of 10 liters of technical hydrogen at known concentration. The second syringe pump from the stand contains 10 liters of air. Both gases are circulated from syringes with the help of stepper motors and mechanical couplings, through the circuit without valves allowing them to enter a homogenization chamber, seen in Figure 2. From here the obtained mixture concentration is verified with the two methods, direct reading from the display of a professional multi gas detector and an Arduino based hydrogen sensor system.

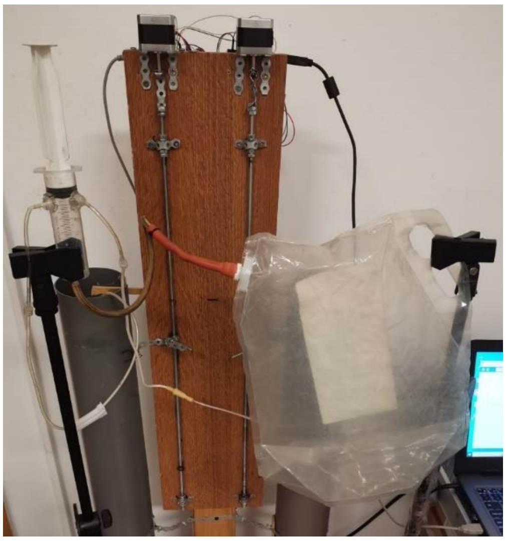


Figure 2. Preparing the hydrogen mixture with the help of an automated stand

The desired concentration value is first introduced from a computer that cooperates with a microprocessor from gas mixed stand. This microprocessor controls 2 drivers for 2 stepper motors, that are powered from a multiple electric source.

3.1 Results from the Arduino based hydrogen sensor

The following table contains the values obtained from the hydrogen sensor after it was exposed to the gas mixture from the sampling bag. The hydrogen sensor used is an MQ-8 semiconductor sensor, widely used in domestic gas leakage alarm, industrial flammable gas alarm and portable gas detector with hydrogen range from 100 to 1000 ppm. Figure 3 represents the moment when the sensor measures the hydrogen released from the sampling bag and Figure 4 captures the output from Arduino Serial Monitor. LED light was inserted in the circuit to detect the presence of hydrogen.

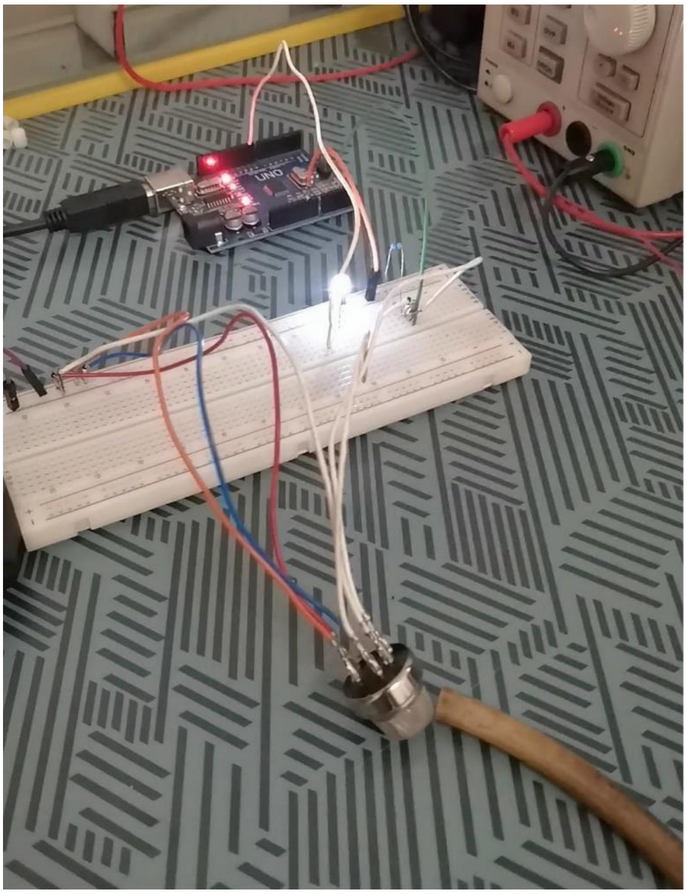


Figure 3. Hydrogen sampling to MQ-8 sensor

Table 5. Gas values readings and interpretation from hydrogen sensor.

Sensor reads	Calculation of H_2	Determined H_2 (%)	Determined H_2 (ppm)
31.0	31.0 / 1023	0.0303%	303 ppm
30.0	30.0 / 1023	0.0293 %	293 ppm
29.0	29.0 / 1023	0.0283 %	283 ppm
32.0	32.0 / 1023	0.0312 %	312 ppm
30.0	30.0 / 1023	0.0293 %	293 ppm
28.0	28.0 / 1023	0.0273 %	273 ppm
27.0	27.0 / 1023	0.0263 %	263 ppm
26.0	26.0 / 1023	0.0254 %	254 ppm

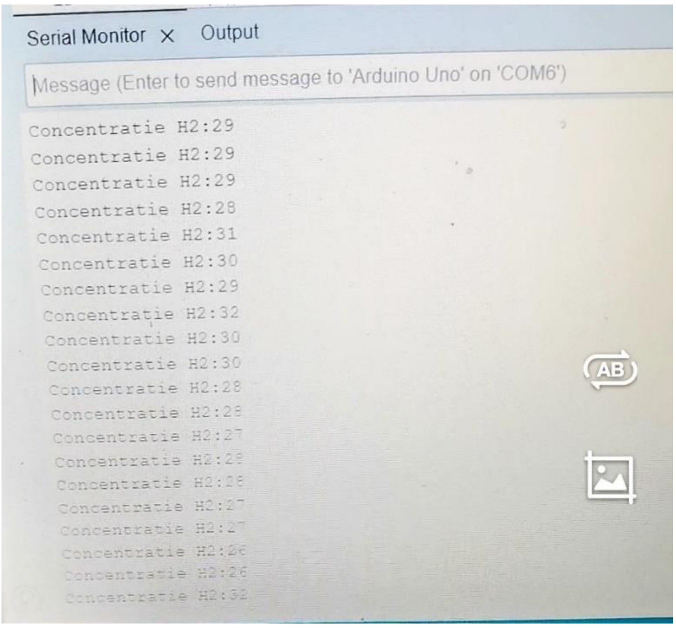


Figure 4. Output results from Arduino Serial Monitor

3.2. Results from the multi gas detector

The multi gas detector is equipped with an infrared sensor for methane gas in the 0 to 100 % volume fractions range. In the detector operating manual, the sensitivity set point of 3 % volume fractions, meaning that is 3 times sensitive to hydrogen. The results from the multi gas detector display are detailed in the table below, Tabel 6.

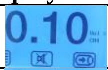
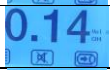
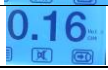
The equivalent of hydrogen concentration from a methane sensor is calculated as follows:

$$\text{Concentration } H_2(\%) = \frac{CH_4 concentration}{\text{Sensitivity ratio}} = \frac{0.10\%}{3} = 0.0333\ \%\ \text{vol.`}$$

$$\text{Concentration } H_2(\%) = \frac{CH_4 concentration}{\text{Sensitivity ratio}} = \frac{0.14\%}{3} = 0.0466\ \%\ \text{vol.}$$

$$\text{Concentration } \mathrm{H_2}(\%) = \frac{CH_4 concentration}{\text{Sensitivity ratio}} = \frac{0.16\%}{3} = 0.0533 \text{ \% vol.}$$

Table 6. Readings on multi gas detector and interpretation of hydrogen through methane sensor.

Sensor reads	Data display on detector	Determined H_2
0.10 % vol.		0.0333% vol. / 333 ppm
0.14 % vol.		0.0466 % / 466 ppm
0.16 % vol.		0.533 533 ppm

4. CONCLUSIONS

The following table summarizes the hydrogen concentration readings from both the Arduino based hydrogen sensor and the professional multi-gas detector, in order to establish the concentration obtained from the automated gas mixer.

Table 7. Comparative results from hydrogen determination.

Arduino hydrogen MQ-8 sensor	Multi gas detector H_2
303 ppm	333 ppm
293 ppm	466 ppm
283 ppm	533 ppm

The systems used in the present paper to validate hydrogen concentration have their strengths and are suitable for different use cases. The version that includes an Arduino board with a hydrogen sensor MQ-8 is customizable, especially used in non-critical applications, while the professional multi-gas detector ensures high quality measurements and accuracy for industrial and safety-focused environments. Comparing the results from both systems, the experimental determination of hydrogen concentration was a real success and the paper now highlights the importance of calibration and the compromise between cost and precision regarding gas detection.

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„GHG INTENSITY” – METRIC THAT SURPASSES „CARBON FOOTPRINT” IN ACCURATELY AND EFFECTIVELY EXPRESSING THE IMPROVEMENT OF A TECHNOLOGICAL PROCESS IN TERMS OF CARBON EMISSIONS’ REDUCTION

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Abstract: *As officialdoms, in estimating carbon emissions’ reduction achievements, often use to just look at the „carbon footprint”, which is the total amount of emissions containing carbon (representing Scope 1 – direct, Scope 2 – indirect and Scope 3 – all the rest within the technological process), it is essential for us to emphasize that, actually, there is a much more accurate and effective way to show the extent in which a certain technological process affects the environment in terms of carbon emissions. Explicitly, this can be achieved by punctually looking at emissions per unit of product, using a new metric called „GHG intensity”, which represents the amount of carbon dioxide equivalent emitted per product, denoted as* CO_2eq*, that sometimes might be decreased even in a certain situation when the total amount of emissions appears to be increased. The present paper aims to explain the differences between „carbon footprint” and „GHG intensity” and to examine particular results obtained for some aluminium slabs. This analysis is particularly important in the context in which (climate change and environmental degradation being an existential threat to the entire world and, in particular, for Europe) the European Green Deal recently imposed a challenge, aiming to ensure an efficient and competitive economy in the European Union, requiring for all net GHG emissions to be eradicated by 2050.*

Key words: *GHG intensity, carbon footprint, carbon emissions’ reduction, carbon dioxide equivalent, specific embedded emissions, calculation-based methodology, mass balance, aluminium slabs*

1 INTRODUCTION

Responsible consumption and production have nowadays become a prioritized policy of the European Commission and of the United Nations, this being known as „the 12th global goal” [1-6].

Therefore, ensuring sustainable consumption and production patterns is essential, as the planet has offered us plenty natural resources, but the human kind has not used them in a sustainable way, so latterly the consumption exceeds the planet’s possibilities of regeneration.

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Consequently, we must use and produce in responsible ways, so as to reverse this harm as much as possible, by achieving a sustainable management and an efficient consumption of resources.

The European Green Deal has imposed a target, as to ensure a competitive and efficient economy within the European Union, among others through the requirement that the net greenhouse gas emissions should be eradicated by the year 2050 [7].

All the companies, especially the transnational and large ones, should be encouraged to adopt best practices in order to protect the environment, this resulting in minimizing their ecological footprint by improving the way to use resources and to produce goods.

2 CARBON EMISSIONS' REDUCTION – AN IMPORTANT ECOLOGICAL PURPOSE

Many activities, especially the ones dedicated to conventional energy generating, but also the agricultural ones and the industrial ones end up, without any doubts, releasing atmospheric emissions of greenhouse gases (GHG).

Different GHG are emitted into the atmosphere during the life cycle of a product, process or service (examples of activities that generate emissions are, among others [8, 9]: burning of fossil fuels, creation of pasture for cattle, deforestation, cement production, aluminium production – this last one being the activity taking into consideration within our present case study).

Among GHG, carbon dioxide (CO_2) is the main one, but there also are other ones containing carbon, especially perfluorocarbons (PFC), these being mostly represented by perfluoromethane (CF_4), perfluoroethane (C_2F_6) and octafluoropropane (C_3F_8) [10].

Therefore, carbon emissions' reduction is one of the most important purposes in achieving „the 12th global goal", in order to protect the environment.

2.1 „Carbon footprint" – a parameter used to show carbon emissions' reduction

In describing the level of achieving „the 12th global goal", „carbon footprint" is often the main parameter to be taken into account [1-6].

First of all, we must state that carbon footprint is a measure of the carbon equivalent (more exactly, carbon dioxide equivalent) emitted into the atmosphere during a technological process.

As is well known, carbon dioxide equivalent (CO_2 equivalent, abbreviated as CO_2-eq [11]), represents a metric measure that compares the emissions from various GHG from their global warming potential point of view, by converting the amounts of any other GHG to the equivalent amount of CO_2 exhibiting the same global warming potential.

In other words, the carbon footprint examination is a methodology created to measure GHG in which the amount of all emitted gases containing carbon – regardless of the exact type of them – are converted into CO_2-eq.

It is important to note that the carbon footprint is part of the so-called „ecological footprint", defined by Rees and Wackernagel as the impact of an activity or of a whole company, organization, government or any other community on the environment [12], *i.e.*, a methodology that measures the extension of the part of Earth needed to sustain it (carbon footprint is part of „ecological footprint", as, in some extent, CO_2 could be absorbed by oceans and forests, which are bioproductive areas).

Through the carbon footprint we can analyze the impacts we have on the atmosphere and the climate changes caused by the release of greenhouse gases from each product, process or service we consume.

Every human activity has some impact on the planet [13-16], no matter how small, and the contemporary way of life emits much more gases than the Earth is capable of absorbing, in other words, we are demanding a lot of its biocapacity.

One might see that the carbon footprint nowadays represents more than half of the ecological footprint, being the fastest growing factor since the end of the last century, when the carbon footprint represented less than a quarter of the ecological footprint.

Different standards and protocols refer to the carbon footprint. Namely, GHG protocol is a widely used method for formulating GHG inventories, by analyzing emissions in organizations' value chains and being compatible with ISO standards and IPCC quantification methods; PAS 2050 quantifies GHG emissions in the life cycle of a company's products and services with the aim of managing and reducing them, allowing product labeling; ISO 14064 [17] provides several tools for developing greenhouse gas emissions reduction programs to be applied in industry and government for more sustainable actions, whereas ISO 14067 specifies principles, requirements and guidelines for quantifying and reporting the products' carbon footprint.

2.2 „GHG intensity" – a more accurate metric to define carbon emissions' reduction

Although carbon emissions' reduction achievements are frequently looked at as the total amount of emissions in a certain technological process (representing Scope 1 – direct, Scope 2 – indirect and Scope 3 [18] – all the rest within the technological chain), this point of view might be subjective and consequently not quite appropriate to express whether that particular process has been improved or not in terms of carbon emissions' reduction, as carbon offsetting or neutralization, in addition to making environmental projects financially viable, improves and promotes people's quality of life.

For example, the same amount of CO_2 emitted by two companies can be compensated with incentives and the use of clean technologies by only one of them (as unavoidable emissions can be compensated in certified environmental projects), which, of course, matters a lot.

Or, for the same company, the activity level might increase, whereas the carbon footprint per production unit might decrease, as a result of upgrading the technological process. In this case, it could seem that the general carbon footprint is increased!

To understand this, let us draw a very simple scheme (Figure 1), in which the activity level is increased three times (by passing from a single production unit to three production units), whereas the carbon footprint per production unit is decreased to half of the initial value, by a technological improvement. In this case, the final overall carbon footprint is increased 1.5 times, so, at first glance, one might say that this was not a progress in ecological terms, but, of course, such a conclusion is not the proper one (clearly illustrating that „GHG intensity” is a metric that surpasses „carbon footprint”)!

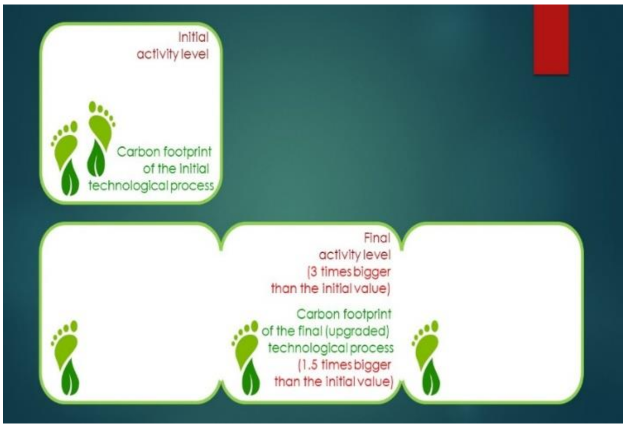

Figure 1. Scheme illustrating that „GHG intensity” is a metric that surpasses „carbon footprint”

Consequently, in order to systematically describe sustainability, we have to introduce a further notion referring to GHG (greenhouse gases), namely „GHG intensity”.

The indicator is calculated as the ratio of energy-related GHG emissions to the energy consumption. It expresses the amount of CO_2 equivalent (CO_2-eq) that is emitted in a given economy per unit of material consumed (obviously, energy emissions data come from official GHG emissions reports).

Admitting that we must deepen the analysis of the role of intensity indicators that are relevant for the design and implementation of economic instruments that aim to reduce GHG emissions, but recognizing that the concept of intensity can be incorporated in different contexts, assuming different purposes, in the context of climate change, in addition to emissions intensity indicators (carbon intensity indicators), energy intensity indicators are equally important.

An important first step in conducting the proposed exercise is to carry out a conceptual review to qualify what can be understood as an intensity indicator. So, considering that intensity indicators find applications at different levels of planning and can refer to organizations, communities, sectors and countries, constituting a useful tool for both public and private managers, examples of the application of these indicators in different contexts can be presented, starting from the most comprehensive level to the most specific.

In order to reduce its emissions intensity, the companies continuously should invest in modernization projects that include efficiency in industrial processes, reduction in the consumption of fossil fuels, reduction in energy use, purchase of more efficient equipment, among others.

Different areas and operations of a certain company should map technologies and should develop studies for submission and approval of projects which promote the reduction of GHG emissions.

It is also worth highlighting that some companies are already called „carbon positive”. This expression means that the CO_2 removals of such a company are greater than its emissions, but, however, such a company should continue to invest and constantly pursue the reduction of the intensity of its emissions and should continuously work to expand its removal capacity, in order to protect the environment.

3 CALCULATION-BASED METHODOLOGY

Monitoring the direct emissions will be presented within „calculation-based methodology” (another option would be to follow the „measurement-based methodology”, consisting in measuring GHG concentration directly in the stack or using extractive procedures and measure flue gas flow in order to determine emissions, which is not so appropriate in our case study [19]).

3.1 Defining the system boundaries

The first step in determining specific embedded emissions is to define the system boundaries associated with the production process [19].

As an example, we will take the primary smelting production route of unwrought aluminium (ingots).

The scheme for it is presented in Figure 2.

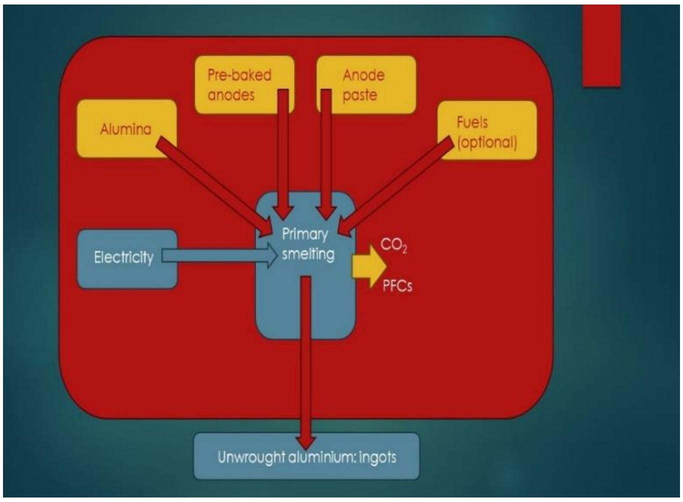

Figure 2. Scheme defining the system boundaries associated with the production process

3.2 Identifying the most relevant parameters and methods in carrying out monitoring

The second step in determining specific embedded emissions is to identify which are the most relevant parameters and methods in order to carry out the monitoring [19].

Before calculating the actual mass balance, we can proceed with the standard method, which consists in determining the quantities of fuels and input materials consumed, then determining some important calculation factors – such as the net calorific value or the emission factor) and lastly determining the emissions by multiplying the input (*i.e.*, the consumption) with the respective calculation factors, previously determined.

So, denoting emissions by $Emis$, the emission factor by $EmisF$ and the whole consumption by $Input$, we can write:

$$Emis = Input \cdot EmisF \tag{1}$$

Beside CO_2, emissions of perfluorocarbons (PFC), mostly represented by perfluoromethane (CF_4), perfluoroethane (C_2F_6) and octafluoropropane (C_3F_8) [10] – resulting from the reaction of the carbon anodes with the molten cryolite – should also be taken into account.

High-voltage PFC emissions (caused by anode effects) are usually determined by using the overvoltage method or the slope method, whereas low-voltage PFC emissions (other kinds of PFC emissions) remain to be estimated by using industry best available practices.

The actual mass balance consists in: determining the carbon content within all fuels and input materials, together with determining carbon content in all fuels and output materials, followed by determining emissions as the difference between inputs and outputs, which is characteristically relevant in the processes in which carbon remains in the goods produced.

Keeping the same interpretation for $Emis$ and $EmisF$, we can write:

$$Emis = \left(\sum_{i=1}^{m} C_{i,fuel} + \sum_{j=1}^{n} C_{j,input} - \sum_{k=1}^{q} C_{k,output} \right) \cdot EmisF \tag{2}$$

where:
m = the total number of fuels;
n = the total number of input materials;
q = the total number of output materials;
$C_{i,fuel}$ = the carbon content within the i^{th} of the m fuels;
$C_{j,input}$ = the carbon content within the j^{th} of the n input materials;
$C_{k,output}$ = the carbon content within the k^{th} of the q output materials.

3.3 Attributing emissions to production process

Attributing emissions to production process consists in two parts: attributing direct emissions and attributing indirect emissions [19].

On one side, attributing direct emissions should be made by the following equation:

$$AttrEmis_{dir} = Emis_{MH,imp} - Emis_{MH,exp} + Corr_{WG,imp} - Corr_{WG,exp} + DirAttrEmis + Emis_{el.prod} \quad (3)$$

in which:
$AttrEmis_{dir}$ = attributed direct emissions of the production process;
$Emis_{MH,imp}$ = emissions related to the attribution of measurable heat imported;
$Emis_{MH,exp}$ = emissions related to the attribution of measurable heat exported;
$Corr_{WG,imp}$ = correction for imported waste gases;
$Corr_{WG,exp}$ = correction for exported waste gases;
$DirAttrEmis$ = directly attributable emissions as linked to source streams (others than measurable heat or waste gases);
$Emis_{el.prod}$ = emissions related to electricity production (if any; for the concrete example that we are going to take, referring to aluminium slabs, this last factor will not be present).

On the other side, attributing indirect emissions to production process should be made by the following equation:

$$AttrEmis_{indir} = E_{el.cons} \cdot EmisF_{el} \quad (4)$$

in which:
$AttrEmis_{indir}$ = attributed indirect emissions of the production process;
$E_{el.cons}$ = electricity consumed;
$EmisF_{el}$ = emission factor of electricity.

For this last factor, one should generally use either the average emission factor in the respective country or other an emission factor based on oficially available data.

3.4 Calculating the specific emissions embedded within the products

Calculating the specific embedded emissions consists in two parts: calculating the specific embedded emissions for simple goods and calculating the same for complex goods [19].

On one hand, for simple goods, calculating the specific emissions embedded within them should be made by the following pair of equations and then adding the results to one another:

$$SEE_{SGdir} = \frac{AttrEmis_{SGdir}}{Amt_{SG}} \tag{5}$$

$$SEE_{SGindir} = \frac{AttrEmis_{SGindir}}{Amt_{SG}} \tag{6}$$

$$SEE_{SG} = SEE_{SGdir} + SEE_{SGindir} \tag{7}$$

where:
SEE_{SGdir} = specific direct emissions embedded within simple goods;
$SEE_{SGindir}$ = specific indirect emissions embedded within simple goods;
SEE_{SG} = total specific emissions embedded within simple goods;
$AttrEmis_{SGdir}$ = direct emissions attributed to simple goods;
$AttrEmis_{SGindir}$ = indirect emissions attributed to simple goods;
$AttrEmis_{SG}$ = total emissions attributed to simple goods;
Amt_{SG} = amount of simple goods produced.

On the other hand, for complex goods, calculating the specific emissions embedded within them should be made by the following set of equations:

$$SEE_{CGdir} = \frac{AttrEmis_{CGdir}}{Amt_{CG}} \tag{8}$$

$$SEE_{CGindir} = \frac{AttrEmis_{CGindir}}{Amt_{CG}} \tag{9}$$

$$SEE_{CG} = SEE_{CGdir} + SEE_{CGindir} + \sum_{i=1}^{n} SEE_{Pi} \cdot Amt_{Pi} \tag{10}$$

where:
SEE_{CGdir} = specific direct emissions embedded within complex goods;
$SEE_{CGindir}$ = specific indirect emissions embedded within complex goods;
SEE_{CG} = total specific emissions embedded within complex goods;
$AttrEmis_{CGdir}$ = direct emissions attributed to complex goods;
$AttrEmis_{CGindir}$ = indirect emissions attributed to complex goods;
$AttrEmis_{CG}$ = total emissions attributed to complex goods;
Amt_{CG} = amount of complex goods produced;
n = the total number of precursors;
Pi = the i^{th} of the n precursors;
SEE_{Pi} = specific (direct or indirect) emissions embedded within Pi;
Amt_{Pi} = amount of Pi used per complex goods produced.

4 CASE STUDY – ECOLOGICAL IMPACT OF PRODUCING ALUMINIUM SLABS

In order to obtain aluminium slabs, *i.e.*, mainly during the electrolytic reduction process of alumina, there are some technologies and operational controls that contribute positively to the reduction of atmospheric emissions, such as: electrolytic bath level control, technology and procedures for controlling anode effects, technology and procedures for predicting and suppressing anode effects, technology and procedures for adding alumina to electrolytic vats, formulation of anode component inputs, technology and procedures for placing and removing pins on the anode, efficiency of the electrolytic tank exhaust system [19].

4.1 An overview on the aluminium slabs production

For easily understanding the above, in Figure 3 we present an overview, *i.e.*, a simplified scheme of the actions which might lead to a significant reduction of the ecological footprint, even though the aluminum production has been substantially increased.

So, Figure 3 offers a schematic representation of identifying the most relevant parameters and methods in carrying out monitoring.

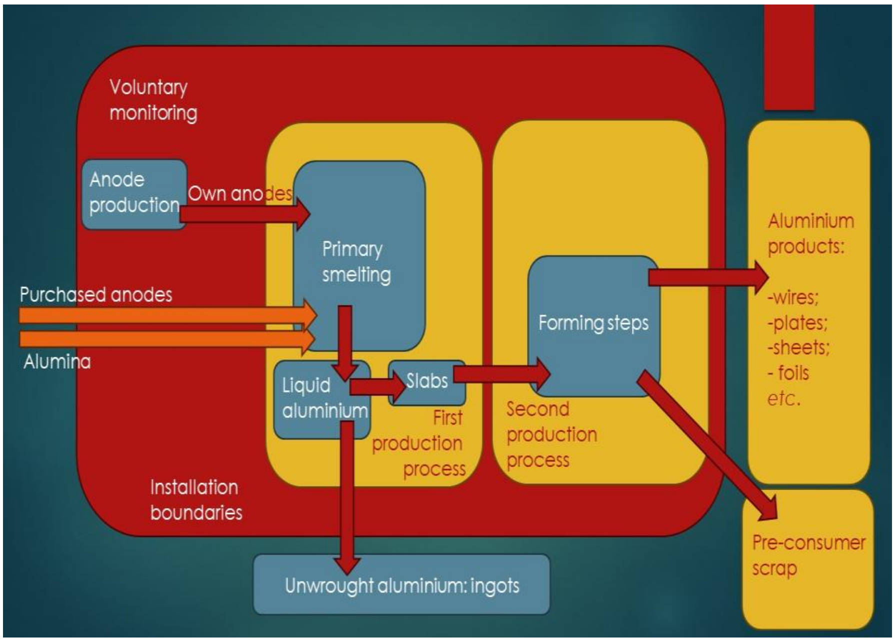

Figure 3. Overview: the most relevant parameters and methods in carrying out monitoring

4.2 Direct emissions sources within the aluminium slabs production

In Figure 4, the main source streams for monitoring the direct emissions are schematically presented.

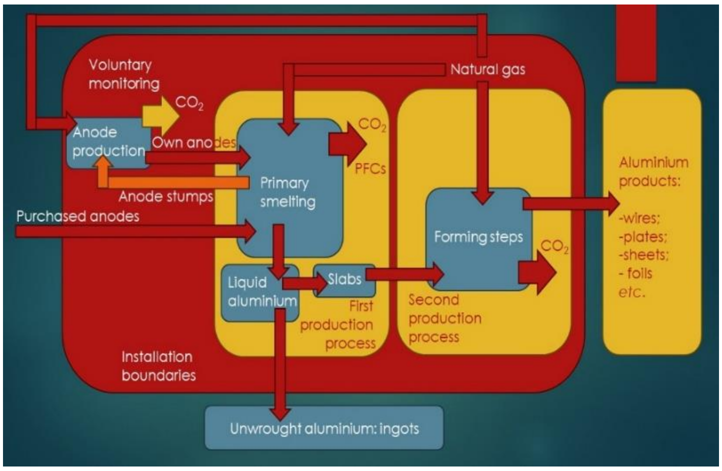

Figure 4. Main sources of direct emissions within the aluminium slabs production

4.3 Indirect emissions sources within the aluminium slabs production

In Figure 5, the main source streams for monitoring the indirect emissions are schematically presented.

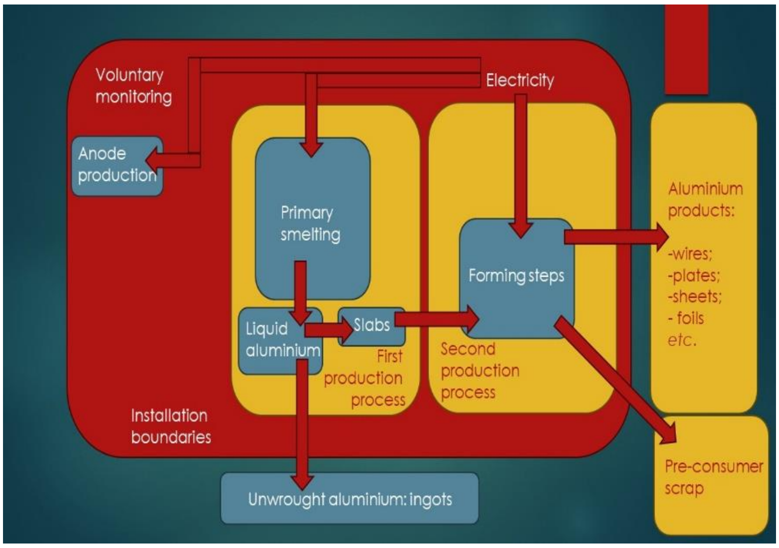

Figure 5. Main sources of indirect emissions within the aluminium slabs production

4.4 A particular example of calculating „GHG intensity” for different aluminium slabs

Following all the steps theoretically presented above, we have calculated „GHG intensity” for three kinds of aluminium slabs, differing by percentage of scrap embedded. Namely, we have started with an example of aluminium slab with no scrap embedded; then, we have continued with an example of aluminium slab with half scrap embedded and we have finished with an example of aluminium slab with three quarters scrap embedded.

For these particular examples that we have chosen, we have used the „energy label” given for Romania within the annual ANRE Report corresponding to the year 2022, in which the emissions have been found as being equal to 223.25 g CO_2/kWh [20].

All the results thus obtained have been gathered and they are presented bellow within three tables (Table 1-3).

Table 1. Example of „GHG intensity” calculation for an aluminium slab with no scrap embedded

	Scope 1 (t CO_2-eq / t Al)	Scope 2 (t CO_2-eq / t Al)	Scope 3 (t CO_2-eq / t Al)	TOTAL (t CO_2-eq / t Al)
Anodes	0.15	0.03	N/A	6.79
Alumina	N/A	N/A	1.7	
Electrolytic aluminium (100%)	1.73	3.18	N/A	

Table 2. Example of „GHG intensity” calculation for an aluminium slab with 50% scrap embedded

	Scope 1 (t CO_2-eq / t Al)	Scope 2 (t CO_2-eq / t Al)	Scope 3 (t CO_2-eq / t Al)	TOTAL (t CO_2-eq / t Al)
Anodes	0.15	0.03	N/A	4.47
Alumina	N/A	N/A	1.70	
Electrolytic aluminium (50%)	0.77	1.61	N/A	
Scrap (50%)	0.19	0.02	N/A	

Table 2. Example of „GHG intensity” calculation for an aluminium slab with 75% scrap embedded

	Scope 1 (t CO_2-eq / t Al)	Scope 2 (t CO_2-eq / t Al)	Scope 3 (t CO_2-eq / t Al)	TOTAL (t CO_2-eq / t Al)
Anodes	0.15	0.03	N/A	3.26
Alumina	N/A	N/A	1.70	
Electrolytic aluminium (25%)	0.40	0.82	N/A	
Scrap (75%)	0.14	0.02	N/A	

By comparing the results above, one might see that total amount CO_2-eq (tons) emitted per same amount of aluminum (tons) exhibits the biggest value in the first one (aluminium slab with no scrap embedded), getting smaller in the second case (aluminium slab with half scrap embedded) and being even further reduced in the third case (aluminium slab with three quarters scrap embedded).

In other words, „GHG intensity” has been decreased as the percent of scrap embedded has been increased, which does not occur only in these particular cases that we have chosen, being a generally valid statement [21].

6 CONCLUSIONS

As over the years the aluminium industry has been worldwide investing in technological modernization (*e.g.*, by introducing or improving electronic systems for measurements, by anticipating and suppressing the occurrence of anode effects, by introducing or reinforcing compliance with more operational practices in order to maintain process stability and to enable operators to act with faster suppression of anode effects – knowing that all the improvements in the characteristic features of anodes also increased the stability of the process, the occurrence of hazardous events was significantly reduced and so was the total amount of GHG emissions and implicitly „GHG intensity”, which is a metric that surpasses „carbon footprint” in describing the actual environmental impact of a technological process. It is obvious that, in determining „GHG intensity”, the concentration of the utilized carbon-containing materials matters a great deal.

Taking for exemplification aluminium slabs production, we have presented within the current work the manner in which „GHG intensity” is influenced by the percent of scrap embedded within the respective aluminium slabs. Concretely, by analyzing different situations, it has been shown that, in order to decrease „GHG intensity, it would be highly recommended to maximize the percent of embedded scrap in the aluminum slabs.

Nevertheless, it is imperatively necessary to note that the quantity (and implicitly the percent) of the scrap cannot be increased however much in the production recipe of aluminum slabs (there even are some special aluminum alloys that do not permit for more than a quarter of the final product to be represented by scrap –

such as the ones used in the aerospace industry, auto industry or in manufacturing vessels designed to work under pressure).

In the end, it is worth noticing that, if „GHG intensity" that corresponds to a certain aluminium product gets to be lower than a limit-value of 4 t CO_2-eq / t Al (as in the last case we have presented), the respective product is called as „green" (production of „green" aluminium products obviously being planned and encouraged, especially within the current context, in which the European Green Deal recently imposed a new challenge, so as to ensure a competitive and efficient economy in the European Union, requiring for all net GHG emissions to be eradicated by 2050).

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METHODS OF ISOLATING BUILDINGS IN ORDER TO REDUCE THE LEVEL OF NOISE POLLUTION INSIDE THEM

Aurora STANCI[1]

Abstract: *The problems related to noise pollution inside the buildings are actual topical and of interest. With the development of road infrastructure and industry, significant problems have arisen related to noise levels inside buildings. In order to reduce the level of pollution inside buildings, solutions must be found to reduce it both at the source and at the receiver. To reduce the level of pollution at the receiver, insulating construction materials can be used to reduce the level of pollution inside the building. In this paper we aimed to study the reduction of noise pollution in buildings using different construction materials. The study was carried out with the help of a model of a house, a model that represents a construction structured in four walls with different composition.*

Key words: *noise, pollution, insulation*

1 INTRODUCTION

An important factor in increasing the quality of life is reducing noise pollution. The term pollution (lat. pollo, polluere - to pollute, to profane) denotes any activity that, by itself or by its consequences, brings changes to biological balances, negatively influencing natural and/or artificial ecosystems with negative consequences for economic activity, the state health and comfort of the human species.

Noise pollution represents an important component of environmental pollution, both by its harmful nature and by its presence in all compartments of modern life, constituting a major problem for all economically developed or developing countries. Noise pollution represents continuous aggression, determined by different noises produced by machines, equipment, industrial or household equipment, inside or outside buildings, noises favored by their location and constructive isolation.

Noise pollution has a destructive impact on the natural balance, endangering the lives of people, animals and plants, through repeated exposure to the noise factor.

The development of all industrial branches, the evolution of technology, the desire for a strong economy, the support of certain interests, have taken a back seat to the protection of maintaining the quality of environmental factors, of life in general.

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The location of factories, refineries, thermal power plants and other large enterprises, with an increased noise factor, in the vicinity of cities, the intensification of the extraction and processing of wood material, have led to an irreversible ecological imbalance. Both humans and animals exhibit debauched behavior due to the need for continuous re-adaptation to a stressful, unpredictable and harmful way of life.

Romania has high noise pollution, over 60% of the urban population is affected by noise due to heavy road traffic. Among the main sources of noise pollution are machines, industrial and agricultural automation, household appliances and equipment (chainsaws, lawnmowers, firearms, toys), cars, trucks and airplanes. Even music, if listened to at a very high volume, especially in headphones, can be just as harmful.

From a physical point of view, sounds are "vibrations of the particles of a medium capable of producing an auditory sensation". Sound is a form of physical energy created by vibrating objects. These vibrations are transmitted in the form of high or low pressure waves that radiate from on the surface of the object.

For this reason, sound insulation is necessary, both in civil and industrial buildings, to stop the spread of noises produced inside and outside the buildings. Noise protection is stipulated as an essential requirement in Council of Europe Directive no. 89/106/CEE and the Interpretative Documents approved on November 30, 1993 and is defined as follows:

"The construction must be designed and executed in such a way that the noise perceived by users or people nearby is maintained at a level that does not affect their health and allows them to sleep, rest and work in satisfactory conditions." [1], [2], [3], [4], [5]

2 THEORETICAL CONSIDERATIONS

Sounds are vibrations transmitted through an elastic medium in the form of waves. For certain intensity and frequency values, sounds are perceived by the human ear, producing auditory sensations.

Sounds can be simple or complex. Disturbing sounds, regardless of their nature, are noises. They have a harmful influence on the nervous system, causing a state of fatigue. For this reason, sound insulation is necessary, both in civil and industrial buildings, to stop the spread of noises produced inside and outside the buildings.

Sounds can propagate through the air, being called airborne sounds or noises, or through solid media (construction elements), being called structural sounds or noises.

The noises produced by blows are called impact noises and are transmitted both through the structure (elements) and through the air.

The weakest sound that can be perceived by humans, at a frequency of 1000 Hz, has the acoustic intensity I0 = 10-12W/m2. On the other hand, it was found experimentally that the auditory sensation increases with the logarithm of excitation. Due to this fact and to avoid the practical difficulties related to the use of very small numbers (10-12...100), for the convenient characterization of the acoustic level, a logarithmic scale is used, related to a reference intensity, according to the relationship:

$$L_i = \log I - \log I_0 = \log \frac{I}{I_0} \tag{1}$$

where: Li – sound intensity level (Beli); I – acoustic intensity (W/m2); Io – reference acoustic intensity (W/m2); it represents, by definition, the lower threshold of auditory intensity that can be perceived by humans, at the frequency of 1000 Hz; log – logarithm in base 10.

The current subunit used in calculations and measurements is the decibel (denoted dB), in which case relation (1) becomes:

$$L_i = 10.\log \frac{I}{I_0} \tag{2}$$

Acoustic sources are bodies that emit acoustic energy in space. Thus, a local disturbance of the pressure is produced, propagating from nearby to nearby in the surrounding environment.

Some sources radiate acoustic energy evenly in all directions, while others (the most numerous) radiate most of the energy in certain directions. In the first case the source is non-directional or omnidirectional, and in the second case the source is directional.

For an omnidirectional source located in the free field, between the pressure level at a certain distance from the receiver and the power level there is the relation 3:

$$L_p = 10\ log \frac{W}{4\pi d^2} = L_W + 10\ log \frac{1}{4\pi d^2} \quad \text{[dB]} \tag{3}$$

where :Lp - is the sound pressure level, [dB]; W - is the acoustic power, [W]; Lw - is the sound power level, [dB]; d - is the source-receiver distance, [m].

Another relation between the pressure level at the distance d from the receiver and the power level is the Beranek relation:

$$L_p = L_W - 20 \log d - 11 \qquad \text{[dB]} \tag{4}$$

where :Lp - is the sound pressure level, [dB]; Lw - is the sound power level of the source, [dB]; d - is the source-receiver distance, [m].

When acoustic waves encounter an obstacle, they undergo changes in the direction of propagation and energy characteristics. Thus, part of the sound energy is reflected (Er), part is absorbed by the element (Ea) and part (Et) is transmitted through the element to the surrounding spaces:

$$E = E_r + E_a + E_t \tag{5}$$

The ratio between absorbed and incident acoustic energy is called the absorption coefficient, which varies depending on the nature of the material and the sound frequency:

$$\alpha_a = \frac{E_a}{E} \tag{6}$$

The absorption coefficient for compact construction materials (steel, concrete, brick, wood) has low values, approx. 0.02...0.08, because in these cases the reflected acoustic energy is high. Porous materials (mineral wool, felt, cork) have good sound absorption properties (αa = 0.2...0.8).

The acoustic absorption of a room is determined with the relationship:

$$A = \sum \alpha_i S_i \tag{7}$$

where: αi – the absorption coefficient of the Si surface material; Si – the surface of the construction element "i", or of the objects in the room (m2).

The permissible limits of noise levels in the environment are established according to the characteristics of outdoor activities or in buildings in the respective functional areas, considered as protected or as a source of noise. [1], [2], [4], [6], [7], [8]

Table 1. Admissible limits of noise levels in the environment

Nr.	The considered functional area	Admissible limit of equivalent noise level dB (A)
1	Parks	50 dB (A)
2	Markets, commercial spaces, outdoor restaurants	65 dB (A)
3	Precincts of schools, nurseries, kindergartens, playgrounds	75 dB (A)
4	Industrial premises	65 dB (A)
5	Stadiums, outdoor cinemas	90 dB (A)
6	Car parks	90 dB (A)
7	Car parks with underground service stations	90 dB (A)
8	Railway areas	70 dB (A)

3 RESULTS AND DISCUSSION

For the study we used a model that represents a construction, structured in four walls with a different composition (figure. 1). Does not respect scale parameters.

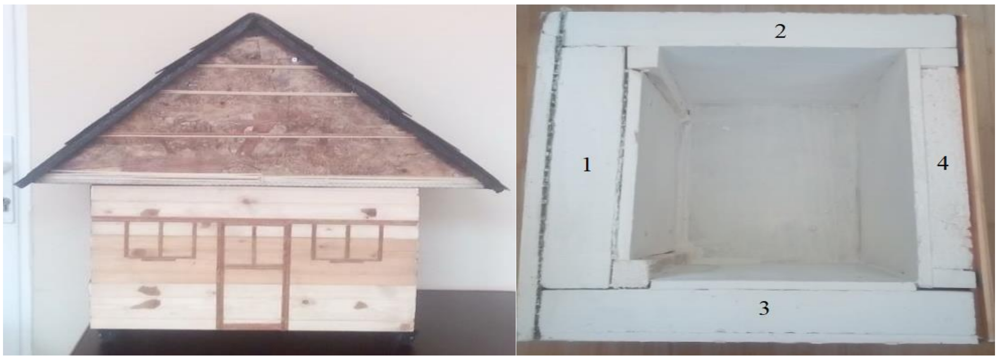

Figure 1. House model

Wall 1 - composition: BCA brick, insulated inside-outside with air bubble foil, inside-outside plasterboard.

Wall 2 - composition: BCA brick.

Wall 3 - composition: BCA brick, interior-exterior plasterboard.

Wall 4 – composition: wood structure, polystyrene insulation.

The idea of using air bubble film came from the desire to create an air cushion, in order to provide sound insulation. Bubble wrap is currently used to protect products against shocks, scratches, pressure, moisture, extreme temperatures, being a light, flexible packaging material.

Figure 2. Sound level meter PCE-222

The device used for these measurements is a PCE-222 multimeter (Fig. 1), it is a multifunctional sound level meter for environmental parameters (with acoustic sensor, light, temperature and relative humidity), with RS-232 interface and Windows compatible software , having an accuracy of ±3.5dB in the measurement of acoustic intensity.

With the help of the sound level meter we determined the sound level. For comparison, we measured the level of noise transmitted through each wall structure, the results being presented below.

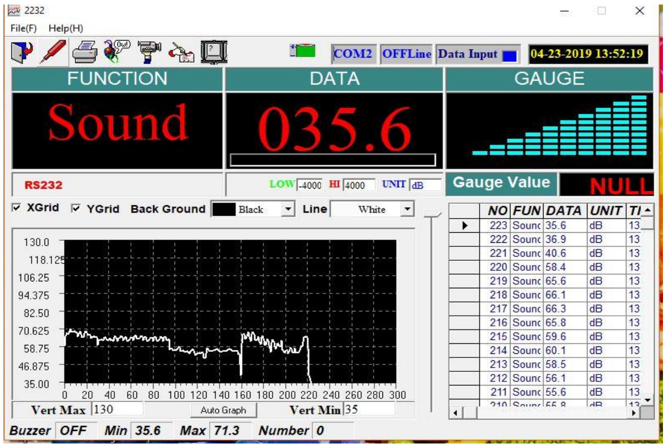

Figure 3. Walls: 4,2,1,3

The graph in figure 3 was obtained with the sound level meter inside the model, the noise source being located on each separate wall. Up to second 60 the composition wall with wood structure, polystyrene insulation, between seconds 60-90 the measurements were made on the BCA brick composition wall, between seconds 90-160 the measurements were made on the BCA brick composition wall, insulated inside-outside with bubble wrap, interior-exterior plasterboard and after sequence 160 measurements were made on the BCA brick composition wall, interior-exterior plasterboard. From the graph it can be seen that the foil wall (1) isolates the noise the best.

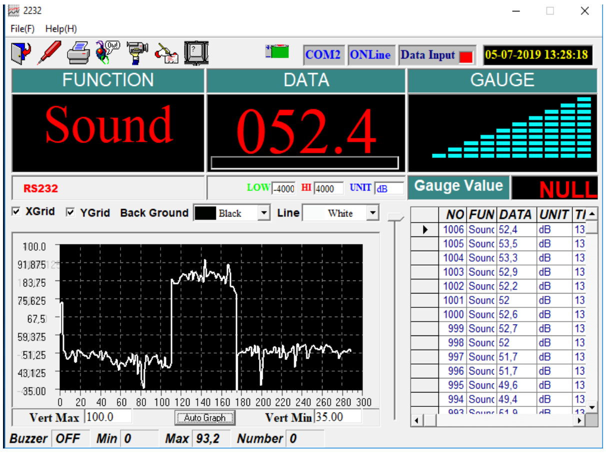

Figure 4. Walls: 1,3

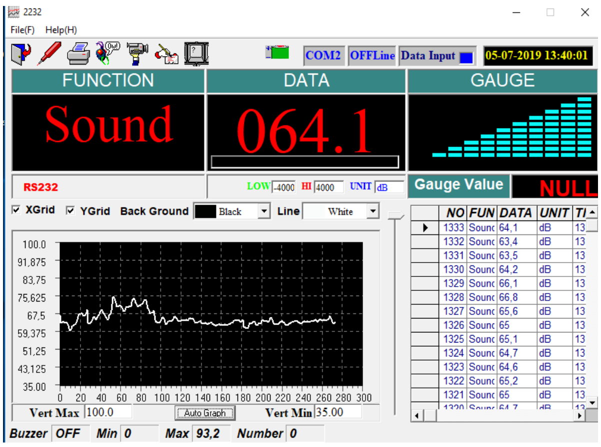

Figure 5. Walls: 2,4

The graphs in Figures 4 and 5 were obtained with the noise source inside the model, with the sound meter placed on each wall separately. In figure 4 up to second 110 the measurements were made on the wall with foil, between seconds 110-170 is the noise produced without any kind of insulation at a distance from the thickness of the wall, between seconds 170-290 the measurements were made with the sound level meter on wall 3 (same structure like wall 1 but without foil). From the graph it can be seen that the foil produces a better sound insulation. The noise measured on the foil wall (1) has values between 43-51 dB and the wall (3) between 51-53 dB

The values obtained for sound insulation in the case of walls 1.3 is much better with values between 43-52 dB compared to the insulation produced by the other 2 walls with values between 59-75 dB wall 2, 59-65 wall 4

5 CONCLUSIONS

Noise pollution has a harmful influence on the nervous system, reducing the cognitive capacities of perception and reaction, causing a state of fatigue, often inducing a state of agitation, insomnia, depression, headaches, dizziness. Its action manifests itself over time, imperceptibly.

More and more often in the medical world people talk about "noise disease", with the damage to the nervous and auditory system.

Noise also affects animals, not only humans, causing them stress, increasing the risk of mortality, communication problems that affect the reproduction and navigation of aquatic organisms, temporary or permanent loss of hearing, habitat restriction that can lead to the disappearance of some species.

Sound insulation is necessary, both in civil and industrial buildings, to stop the spread of noise produced inside and outside the buildings.

From the measurements made, it can be seen that the wall that has in its composition the foil with air bubbles having a thickness of 3mm produces a better isolation of noises.

By using a film with larger air bubbles, the insulation can be increased. This model, with the walls structured in this way, can be used to study the thermal insulation of buildings.

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MONITORING THE LEVEL OF RADIOACTIVITY PRESENT IN THE AIR IN THE MUNICIPALITY OF LUPENI

Aurora STANCI[1]

Abstract: *Environmental monitoring involves supervision, forecasting, warning and intervention in order to systematically evaluate the dynamics of the qualitative characteristics of environmental elements, in order to know the quality state of the environment. One environmental problem is the level of radioactivity in the air. Environmental radioactivity monitoring is done for three purposes, namely knowing the level of radioactivity in the environment, assessing human exposure to radiation and establishing measures for the ecological restoration of areas with increased radioactivity. In this paper I propose to present the results obtained following the monitoring of the level of radioactivity of the air in the Municipality of Lupeni in order to establish the level of environmental radioactivity in this area.*

Key words: *monitoring, radioactivity, air*

1 INTRODUCTION

The term "environmental monitoring" is defined as "surveillance, forecasting, warning and intervention in order to systematically evaluate the dynamics of the qualitative characteristics of environmental factors in order to know the state of quality and their ecological significance, the evolution and social implications of changes products followed by necessary measures".

The existence of an environmental monitoring system results from the following needs:

- the need to know the evolution of the quality of environmental factors in order to establish and impose measures for protection, conservation, re-technology and verification of the effectiveness of the measures taken.
- the need to group, select and order information and correlate it with other information.
- the need to obtain information comparable to regional or global information for their use within own programs or within international programs (world climate, ozone layer, etc.).
- the need to know and quickly evaluate the situation in cases of accidents or anthropogenic incidents.
- the need to develop the knowledge base for establishing environmental protection and ecological reconstruction actions.

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Environmental monitoring corresponds to an objective requirement to obtain a pertinent, overall picture of the state at a given moment and the trend of environmental quality evolution.

The main objectives of environmental quality monitoring:

- identification of pollution sources as part of the quality management system of environmental factors.
- monitoring the discharge of pollutants in various environments (air, water, soil).
- assessment of exposure and risk to population and ecosystems.
- informing the public.
- establishing a scientific basis to be the basis for the development of environmental protection strategies.
- assessing long-term trends as part of environmental management systems.

In general, environmental monitoring systems represent integrated systems made up of monitoring networks on various environmental domains, respectively monitoring subsystems of various environmental factors. [1], [2], [3], [4], [5], [6], [7], [8], [9], [10]

2 RADIOACTIVITY LEVEL MONITORING

Radioactivity is a natural physical phenomenon whereby unstable atomic nuclei spontaneously decompose, emitting radiation in the form of particles or electromagnetic waves. This process is also known as radioactive decay. Radioactivity was discovered in 1896 by the French physicist Henri Becquerel, and it was later extensively studied by Marie and Pierre Curie.

There are three main types of radiation emitted during radioactive decay:

Alpha Radiation (α):

- Consists of two protons and two neutrons (the nucleus of a helium atom).
- Has low penetrating power and can be stopped by a sheet of paper or skin.

Beta Radiation (β):

- Consists of electrons or positrons emitted from the nucleus.
- Has greater penetrating power than alpha radiation, being stopped by a thin sheet of aluminum.

Gamma Radiation (γ):

- Is high-energy electromagnetic waves.
- Has very high penetrating power and requires dense materials such as lead or concrete to be stopped.

Common units of measurement for radioactivity include:

- Becquerel (Bq): Measures radioactive activity, representing one decay per second.
- Curie (Ci): Another unit of measurement for radioactive activity, equivalent to 3.7 x 10^10 decays per second.
- Gray (Gy): Measures the absorbed dose of radiation.

● Sievert (Sv): Measures the effective dose, taking into account the biological effects of radiation.

One environmental problem is the level of radioactivity in the air. Environmental radioactivity monitoring is done for three purposes, namely knowing the level of radioactivity in the environment, assessing human exposure to radiation and establishing measures for the ecological restoration of areas with increased radioactivity. In this paper will be present the results obtained following the monitoring of the radioactivity level of the air in the Municipality of Lupeni in order to establish the level of environmental radioactivity in this area.

The municipality of Lupeni is a municipality located in Hunedoara County, Transylvania, Romania. It is the third largest city of the Jiu Valley, being located in the western part of the Jiu Valley depression, at an altitude of 675-725 m above sea level, at a distance of 18 km from Petrosani and about 110 km from Deva. It is recognized as a mining town, where the Lupeni Mining Company is located.

Figure 1. Municipality of Lupeni

In order to monitor the radioactivity of the environment in the Municipality of Lupeni, measurements were made over a period of 5 days. The detector was placed outside, protected from the sun's rays. The monitoring was carried out between 19.06.2024 and 23.06.2024. The measurements were carried out simultaneously in two areas within the radius of Lupeni Municipality, namely in the area of the Lupeni Mining Exploitation (point one 1) and in the area of the Barbateni neighborhood (point 2). The points where the monitoring was carried out are presented in figure 2.

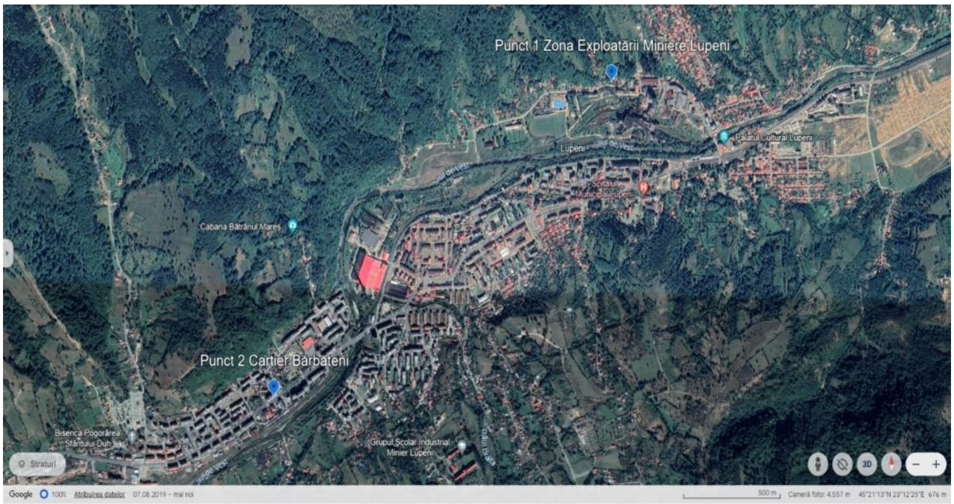

Figure 2. The points where the monitoring was carried out

The measurements were made using the Geiger Gamma Scout radiation detector. Natural radioactivity at various sources can be accurately measured. The Geiger Gamma Scout is used to monitor the impact of ionizing radiation at home and at work. If the ionizing radiation loading is very strong, above 1000 μSv/h (basic nuclear conditions) gamma-Scout displays (NNNN…) and displays the icon ! on the screen for people with occupational exposure to radioactive sources, there are two legal upper limits in the EU. For any values approaching these limits, these individuals must be removed from their exposure environment for some time to return to normal values.

.– 1. The equivalent dose limit is 6 mSv per year (based on the assumption of 2000 working hours per year) = 3μSv/h, Category B.

– 2. The equivalent dose limit is 20 mSv per year = 10 μSv/h, Category A.

The natural environment has a radiation level of approximately 0.1 – 0.2 μSv/h. Below the sensed dose figures on the screen, a bar graph represents the visualization of how long the user can stay in this environment until the ionizing radiation equivalent dose loading of 20 mSv per year, the upper level mentioned for exposed persons, accumulates professional. The measured values can also be analyzed on the computer. This data can also be used in other spreadsheet programs such as Microsoft Excel and transferred. The device allows continuous measurement and recording (data memorization) of radioactivity on the ground (permanent monitoring). The measurement range starts from weak radiation from the environment and reaches high doses of radiation: 0.01 µSv/h to 1,000 µSv/h (legal limit value 20 mSv/year). Detects alpha, beta and gamma radiation. The Gamma Scout radiation detector can permanently monitor the radioactivity on the ground, day and night, the battery lasts about 10 years of continuous use. Types of radiation: alpha (from 4 MeV), beta (from 0.2 MeV) and gamma (from 0.02 MeV). Pulse recording at intervals of 1 min, 10 min, 1 hour, 1, 7 days. [11], [12]

Figure 3. The Geiger Gamma Scout radiation detector

The results obtained after monitoring are presented in figure 4 and 5.

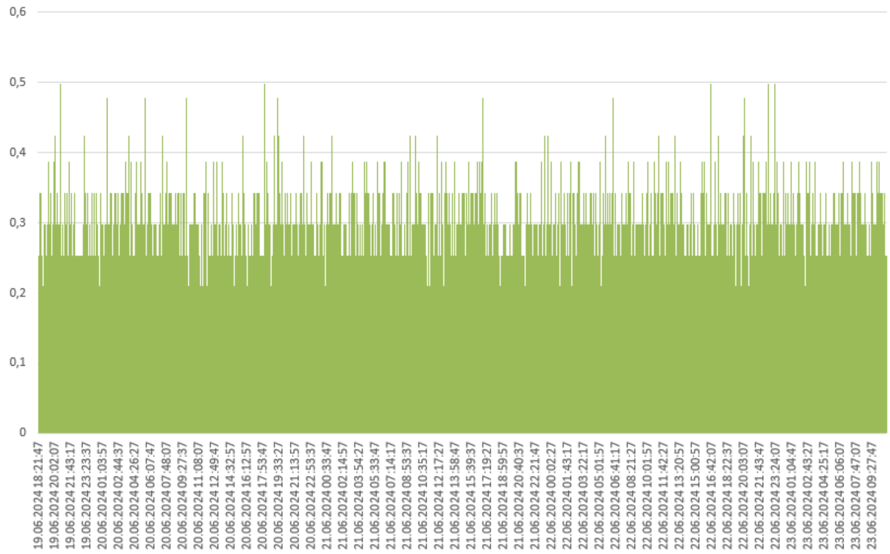

Figure 4. The radiation doses recorded during the monitoring period in the Lupeni Mining area (point 1)

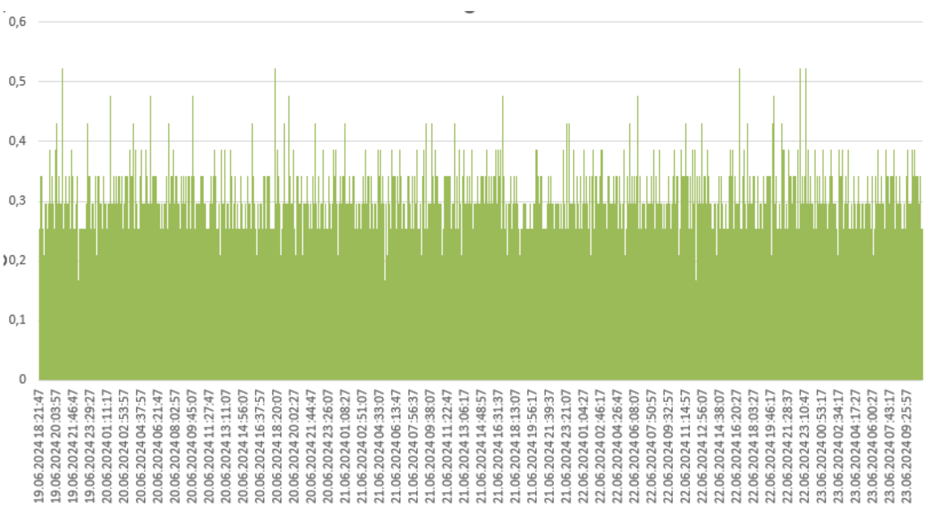

Figure 5. The radiation doses recorded during the monitoring period in the Barbateni area (point 2)

After analyzing the data, we can see that in the radiation monitoring places, the maximum admissible radiation limit is not exceeded and the recorded values are constant. Higher values recorded are measurement errors.

5 CONCLUSIONS

Environmental radioactivity monitoring is done for three purposes, namely knowing the level of radioactivity in the environment, assessing human exposure to radiation and establishing measures for the ecological restoration of areas with increased radioactivity.

The measurements were carried out in two measuring points in order to observe the level of radioactivity in several areas of the Municipality of Lupeni.

From the analyzed data we can see that in Lupeni Municipality the level of radioactivity did not exceed the maximum admissible limit and the recorded values are constant, so it does not affect the environment.

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TECHNICAL AND SAFETY SOLUTIONS FOR THE DEMOLITION BY BLASTING OF A TALL HYPERBOLOID COOLING TOWER

Robert LASZLO [1], Ciprian JITEA[1], Stefan ILICI[1], Aurelian NICOLA[2], Levente MIKLOS[3]

Abstract: *The restructuring of industrial activities involves the carrying out of conservation activities or the decommissioning of buildings or areas that may later be the object of the development of new civil or industrial projects. Many demolitions work by using explosives and are characterized by a high degree of difficulty. This has shown that the use of the blasting technique is a proper alternative from the point of view of efficiency, quality, and security. The paper describes the practical solutions and safety conditions of realizing the demolition of a cooling tower located within a fertilizer plan and having in the very close vicinity several civil constructions. Considering the location of civil construction, the challenge of the project was to find solutions to reduce the throwing distance of the concrete pieces under the action of the explosion, to mitigate vibrations through the collapse and sequential contact with the ground of the construction, and to reduce the value of the overpressure of the air created due to the piston effect during the collapse of the construction of the tower. To establish the possible effects generated by the execution of the tower demolition by blasting works, a risk assessment was made with reference to seismic wave, air shock wave, noise, dust, and the level of shock generated by the impact of constructions with the soil. The demolition works were successfully carried out, and thanks to the technical solutions and the adopted protection and security measures, no damages were recorded.*

Keywords*: explosive, demolition, blasting parameters, risk evaluation, safety*

1. INTRODUCTION

The reorganization of industrial activity leads to the preservation or dismantling of buildings or regions that can subsequently be utilized for the implementation of new projects. Due to its reduced time consumption, labor, and cost, the demolition process with blasting techniques presents a demanding application from a technological standpoint. Extensive demolitions, which include the use of explosives and are known for their challenging nature, have demonstrated that employing the blasting technique is

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a suitable option in terms of effectiveness, quality, and safety. When conducting a building demolition, the primary purpose is to minimize the impact on nearby structures that need to be preserved. This involves minimizing the number of elements destroyed by the blast and reducing the amount of explosives detonated simultaneously.

The explosive charge required to dismantle a particular construction part depends on the type of explosive used, the material being blasted, the type of construction to be demolished, and the geometry of the hole placement. The blasting efficiency depends on the ratio of geometric parameters (anticipation, distance between holes, and hole length), number and size of explosive charges, as well as type of steeming action [2,3].

The paper outlines the practical method for demolishing by blasting an industrial cooling tower situated on an ammonium nitrate production platform. It discusses the technical and safety measures implemented to ensure the cooling tower is successfully toppled in the desired direction, despite the challenging conditions posed by nearby structures and installations.

A risk assessment was conducted to determine the potential secondary effects resulting from the deconstruction of the tower using explosives. This evaluation focused on seismic waves, air shock waves, noise, dust, and the influence of the CPP tower's structure on the land.

The demolition was executed successfully, with no incidents due to the use of protective and safety measures. The seismic wave created by the contact with the ground of the tower was assessed to be non-hazardous, falling below the projected values in the risk assessment.

2. DESCRIPTION OF THE DEMOLITION SITE

The cooling tower objective was located within the built-up area of Tîrgu Mureş, within the premises of Azomures S.A., in the southwest part of the city. Azomures S.A. is developed on a large industrial platform, on which there are many industrial buildings of different heights with different functions: decanters, production buildings, cooling towers, warehouses, annex buildings, etc. (Figures 1 and 2).

Figure 1. Industrial platform site plan

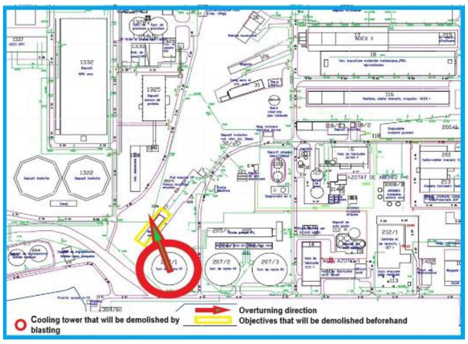


Figure 2. Cooling tower site plan

Within the industrial precinct, the cooling tower is located in the south-western part, parallel to the national road Tirgu Mures – Cluj Napoca. Three identical cooling towers built during the same period are located in this area (Figures 3 and 4).The building to be demolished is one of three cooling towers arranged in the south-western part of the enclosure, namely tower C15. The cooling tower is no longer used for a long time. The middle tower, being rehabilitated more recently, is frequently used and the right tower is used periodically [1].

Figure 3. Area of cooling towers

Figure 4. Cooling tower demolition area

Cooling towers play a role in evacuating waste heat generated by industrial plants into the atmosphere by cooling a stream of hot water to a lower temperature. The cooling tower inside Azomures SA was built in 1962, presenting today an advanced degree of damage to the resistance structure due to the operating situation, unfavorable conditions, and lack of rehabilitation over time.

Given the age of the objective and the fact that it has not been used for several years, it poses an important risk of collapse at the action of the normative earthquake or of the actions in maximum values according to the norms in force, and a functional reconversion of it being expensive and unjustified, the decision was taken to demolish in order to develop other investments in the area freed by constructions.

A demolition company was hired for the execution of preparatory works and of the demolition works themselves by blasting works of the water tower construction.Existing buildings in the direction of overturning the cooling tower (see Figures 2, 3, and 4) were planned to be demolished beforehand by mechanical means [1].

In the immediate vicinity of the demolished cooling tower are the following objectives (Figures 1 and 5):

I. – In the industrial premises of Azomures S.A.:

1.north, northeast, 54.0 m from the tower boundary - pump station; **2.**to the east, 24.0 m from the tower boundary – cooling tower; **3.**to the east, 154 m from the tower boundary - acid manufacturing hall; **4.** to the north-west, 20 - 30 m from the tower boundary - sheds (they will be demolished beforehand); **5.** to the west, 38 m from the tower boundary – industrial railway line; **6.** to the west, 120 m from the tower boundary – phosphorite deposit; **7.** to the north-west, 92 m – unloading plant;

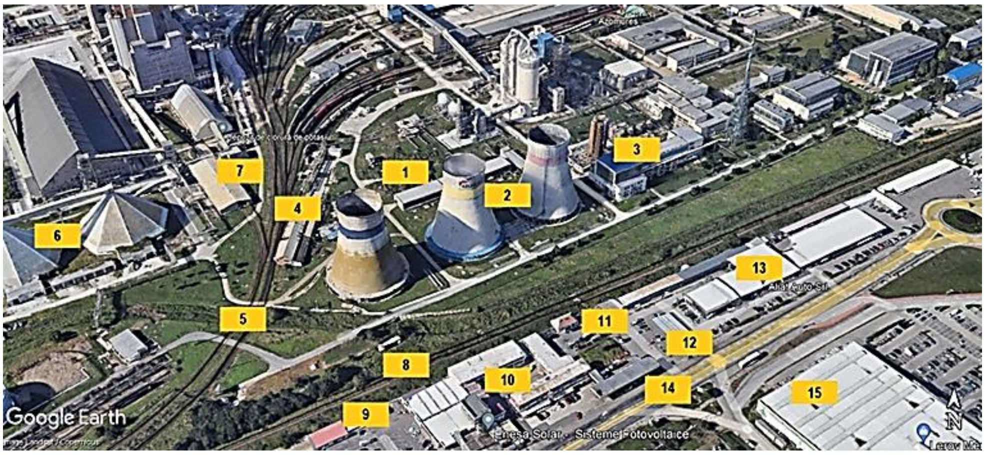


Figure 5. Cooling tower site plan with neighborhoods

II. – Outside the industrial premises of Azomures S.A:
8.to the south, 62 m from the tower limit – railway C.F., Tg. Mures – Ludus;

9. to the south, 184 m from the tower limit – Tg. Mures Customs and Astra Lojistik; **10.** to the south, the 74 m boundary is Turrnului – Enesa Solar; **11.** to thresouth, southeast, 95 – 145 m from the tower boundary – MBO; **12.** to the south, south-east, 152 m from the tower limit – Independent Tg.Mures and MBO auto parts shop; **13.** to the south-east, 135 – 160 m from the tower limit - Aliat Auto SRL; **14.** to the south, 140 m from the tower boundary – European road E60, Gh. Doja; **15.** to the south-east, 210 m from the tower boundary – the southern side of the Leroy Merlin store.

2.1. Cooling tower construction description

The cooling tower to be demolished is in the form of a rotating hyperboloid made of reinforced concrete that slides with a variable section (Figure 6).

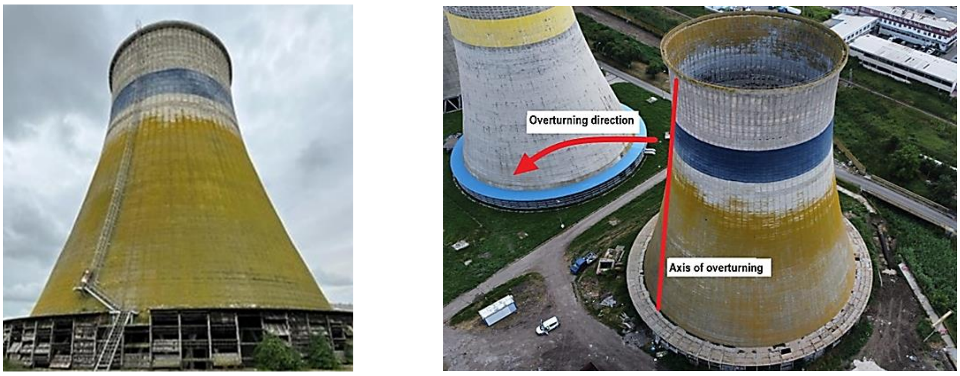


Figure 6. Cooling tower jacket body

The infrastructure part consists of a successive series of circular rings, such as the lower circular ring with T-section consisting of the foundation sole, made inclined, and the wall, which is also used as the wall of the pool at the base of the tower (Figure

7). Then follow the inclined pillars starting from the lower ring in pairs in sets of diagonals that are connected at the upper ends, the circular reinforced concrete abutment belt that forms the starting and abutment base of the tower jacket body (Figure 8).

Figure 7. Base of the cooling tower

Figure 8. Inclined pillars and support belt

In summary, the cooling tower, shaped like a rotating hyperboloid, has a height of 55.00 m with a base diameter of 47.00 m and 21.00 m, respectively, at the top side [1].

The tower structure consists of the following component elements: inclined pillars supporting the tower construction; an annular belt located at the top of inclined pillars; rotating wooden blinds in the area of the windows for air access to the tower; the tower itself, shaped like a hyperboloid; the top side of the tower; the central water distribution chamber in the tower; the resistance structure of the cooling and distribution system at the base of the tower.

The inclined support pillars of the tower are prefabricated of reinforced concrete with an octagonal section, with the main dimensions of 0.45 x 0.40 m. The tower rests on 36 pairs of inclined pillars in the shape of "Λ," with a height of 3.80 m. The ring belt is the main element of resistance and lift of the tower. The belt has a height of 1 m and a thickness of 1 m.

The tower body is the second element of resistance in the construction. The hyperbolic jacket body has a variable thickness in height, ranging from 0.50 m to +6 m and 0.20 to +20 m, and then the thickness of the jacket body remains constant at 0.18 - 0.15 m until below the canopy of the draft tower.

3. DEMOLITION PROCESS

One of the interesting categories of construction, from the point of view of demolition, are the hyperboloid cooling towers. The towers are built of a freely supported structure of reinforced concrete of hyperbolic shape. This structure, apparently fragile, rests at the base on a support consisting of an annular belt and reinforced concrete pillars.

If a scale comparison is made between the thickness of the mantle of the tower and that of the shell of an egg, then the shell of the egg should have a thickness of only 0.1 mm. From this perspective, cooling towers possess a "shell" much thinner than that of an egg. Such constructions take very well the shocks induced from the outside, those of their own weight and temperature variations. A greater unilateral request, however, can be fatal to the stability and integrity of such constructions.

The two main known mechanisms of "failure" of the integrity of the structure of hyperbolic cooling towers as a result of planned collapse are known to be damage to the buckling of the structure and its rotational polarization. two main known mechanisms of "failure" of the integrity of the structure of hyperbolic cooling towers as a result of planned collapse are known to be damage to the buckling of the structure and its rotational polarization.

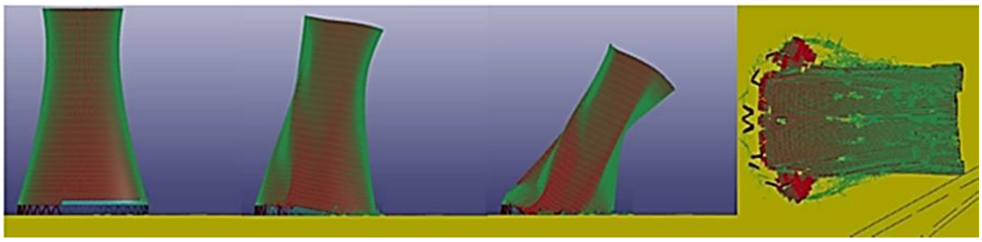
This demolition technique requires that about 60% of the circumference of the jacked body and legs be removed using explosive charges. This will cause the tower to tilt and collapse about five degrees from the vertical.

The tilt mechanism will also cause the hind legs to eventually give way through bending and due to overload. The thicker section of the tower jacket body (commonly referred to as a "beam or annular belt") will collapse and remain almost intact to a height of about 3–5 m, depending on the thickness and configuration of the steel reinforcement within the annular beam. The rest of the jacket body will deform, rotate, and collapse inside the tower over the construction of the water distribution system. It is likely that a small area of the jacket body will be projected outside the footprint of the tower up to a distance of 10–15–20 m. The design distance of these pieces of the tower jacket body can be reduced to a limited extent by using millisecond-delayed blasting of various elements of the structure [4,5,8].

To demolish the tower by blasting, its weakening, respectively, its unilateral collapse tension, is the essential condition for the successful demolition of such constructions. To achieve this demolition mode, breaking sections are executed at the base level, in the pillars supporting the ring belt, in different areas of the ring belt, as well as through vertical and inclined cuts that will be performed in the tower-jacked body with the help of explosive charges consisting of dynamite-type explosives, located in mine holes drilled as specified in this documentation.

After the formation of the breaking section by blasting, in a first phase—at 0.2 sec.—the jacket body of the tower begins to tilt in the direction of overturning, then sinking completely, almost without changing the profile of the entire body of the tower. Meanwhile, due to the action of gravity and cuts created by blasting into the jacket body, it successively crushes into pieces.

In the next phase, at 2 sec., the tower body hits the ground surface with an angle of inclination of about 50 °, and later, at 4 sec., torsion deformation occurs. Finally, at 8 sec., the tower hits the ground and completely disintegrates (Figure 9).



0,2s 2s 4s 8s

Figure 9. Mechanism of collapse of the cooling tower in the range of 0.2 – 8 sec.

4. PREPARATORY STAGES FOR DEMOLITION OF COOLING TOWER STRUCTURE

When choosing the solution for overturning or collapsing the tower, all the above-mentioned aspects were considered. In order to minimize the seismic wave and air overpressure due to the impact with the ground at the collapse of the structure, respectively to create the torsion moment of the tower shell so as to allow the vertical escape of air inside the structure as well as its unfolding into several smaller pieces, with reduced seismic effect on their impact with the ground, it was chosen to create by blasting on 1/2 of the shell perimeter, three discontinuous vertical cuts above the ring belt (elevation +7.0 m), at 1/8 of the perimeter from the cut on the overturning axis, on both sides from the axis of fall, with lengths of 6 - 7 - 8 m on the discontinuity as well as two inclined cuts and continuous towards the back, starting from above the ring belt (elevation +7.0 m), at 1/4 of the perimeter from the cut on the overturning axis, towards both sides of it.

Also, in the area facing the direction of overturning, on 2/3 of the perimeter at the base of the tower, sectioning portions were executed by blasting in the area of the ring belt as well as in the inclined legs supporting the body of the tower. The construction cooling tower was demolished by overturning in the north-east direction on a site free of constructions [1, 3, 5, 8, 9].

To demolish the cooling tower, the following phases were completed:

✓ demolition by classical means of objectives in the direction of overturning of the tower;

✓ decommissioning and cutting the elements of the cooling and distribution system inside the tower (beams and pillars, cooling system support, condensation water collection system) and the connections between them and the jacket / annular belt of the tower on at least 1/3 of the surface in the direction of overturning;

✓ creation of a discontinuous vertical cut on the overturning axis, above the ring belt (elevation +7.0 m). The cut with a width of approx. 0.30 m will have a first section of 6.0 m length (between elevation +6.0 m and +12.0 m) and a second section of 8.0 m length (between elevation + 13.0 m and +21.0 m) with a discontinuity of 1.0 m between the two sections (Figure 10);

✓ creation of 2 discontinuous vertical cuts above the ring belt (elevation +6.0 m) at 1/8 of the perimeter from the cut on the overturning axis, on both sides from the axis of fall. The cut with a width of approx. 0.30 m will have a first section of 6.0 m length (between elevations +6.0 m and +12.0 m) and a second section of 7.0 m length (between elevations +13.0 m and +20.0 m) with a discontinuity of 1.0 m between the two sections (Figure 10);

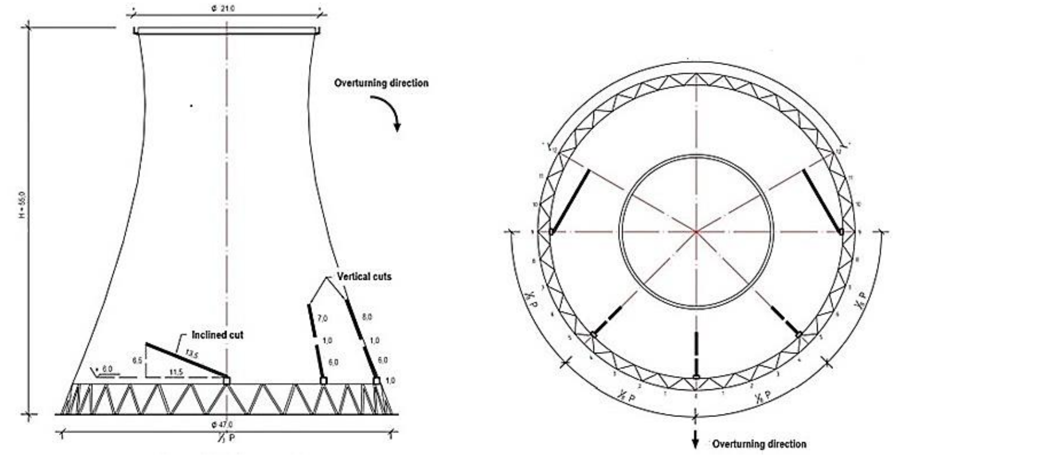
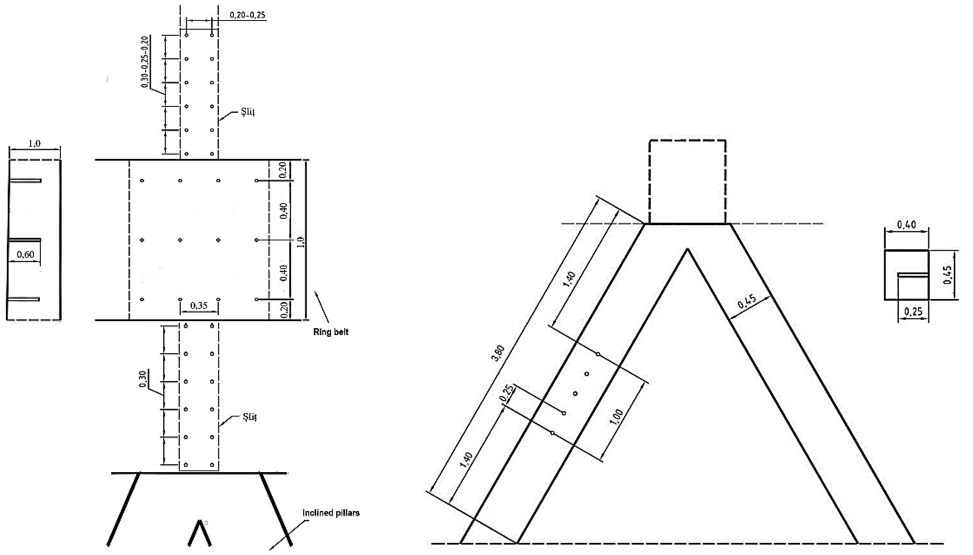


Figure 10. Location of break sections on the shell of the cooling tower



a) b)

Figure 11. Holes location at the level of ring belt, vertical cuts and support pillars

- ✓ creation of 2 inclined cuts and continuous towards the rear, starting above the ring belt (elevation +6.0 m) at 1/4 of the perimeter from the cut on the inversion axis, on both sides from the axis of fall. The cut with a width of 0.30 m and a length of 13.0 m between +6.0 m and +12.5 m has a horizontal projection of 11.50 m and a vertical projection of 6.5 m (Figure 10).
- ✓ creating breaking sections through blasting works, in the ring belt next to the cuts to be executed in the tower jacked body. To make the breaking sections, 16 holes are drilled in a square grid, of 4 holes by 4 rows, with a distance between holes / rows of 0.35 / 0.40 m (Figure 11a).
- ✓ creating a 1.2 m long cut and 0.35 m wide in the tower shell, in the area of the breaking sections of the ring belt, directly below it and in the same alignment with the cuts above the ring belt (Figure 11 a);

✓ creation of breaking sections by blastting works, in the inclined pillars in the half of the perimeter from the direction of fall, respectively 19 pairs of pillars.In order to achieve the breaking sections, 5 holes are drilled in each pillar, starting at +1.4 m (Figure 11b);

✓ manual hammering and cutting of metal reinforcements, at a height of 1.0 from the ground, of 1/2 of the section of the pillars supporting the canopy, located in the half perimeter from the direction of fall.

5. BLASTING PARAMETERS

The explosive charges were dimensioned according to the section of the construction elements to be blasted [1,3,5]:

For the 19 inclined pillars pairs of reinforced concrete, with section 0.45 x 0.40 m, are the following drilling & blasting parameters (Fig. 11 b):

- hole length, l_h = 0,25 m;
- explosive charge per hole, Q_h = 0,05 kg;
- total number of holes, N_{th} = 5 holes x 38 pillars = 190;
- total explosive charge, Q_t = 9,5 kg and 230 lm of detonating cord (≈ 3 lm/pillar).

For the breaking sections in the ring belt, are the following drilling & blasting parameters (Fig. 11 a):

- hole length, l_h = 0,60 m;
- explosive charge per hole, Q_h = 0,100 kg;
- total number of holes, N_{th} = 5 sections x 16 holes = 80 holes;
- total explosive charge, Q_t = 5 sections x 1,6 kg = 8,0 kg and 50 lm of detonating cord (≈ 10 lm/section).

For the creation of vertical and inclined cuts on the tower body, are the following drilling & blasting parameters (Fig. 11 a):

a) vertical cut in the position of overturning axis:

Section I, +6,0m / +12,0 m:

- number of horizontal rows, N_r = 25;
- total number of holes per section, N_h = 50 holes;
- total explosive charge, Q_t =1,5 kg and 30 lm of detonating cord.

Section II, +13,0m / +21,0 m:

- number of horizontal rows, N_r = 48;
- total number of holes per cut, N_h = 96 holes;
- total explosive charge, Q_t =2,4 kg and 50 lm of detonating cord.

b) vertical cuts placed at both sides at 1/8 of the tower perimeter:

Section I, +6,0m / +12,0 m:

- number of horizontal rows, N_r = 2 x 25 = 50;
- total number of holes per cuts, N_h = 2 x 50 = 100 holes;
- total explosive charge, Q_t = 2 x 1,5 kg = 3,0 kg. and 2 x 30 lm = 60 lm of detonating cord.

Section II, +13,0m / +20,0 m:

- number of horizontal rows, N_r = 2 x 43 = 86;
- total number of holes per cuts, N_h = 2 x 86 = 172 holes;

- total explosive charge, Q_t = 2 x 2,5 kg = 5,0 kg. and 2 x 50 lm = 100 lm of detonating cord.

c) inclined cuts placed on both sides, at ¼ of the tower perimeter, elevation + 6,0 – 12,5 m:

- number of horizontal rows, N_r = 2 x 67 = 134;
- total number of holes per cuts, N_h = 2 x 134 = 268 holes;
- total explosive charge, Q_t = 2 x 4,0 kg = 8,0 kg. and 2 x 70 lm = 140 lm of detonating cord.

d) cuts placed vertically under the breaking sections of the ring belt, elevation +3,8 – 5,0 m:

- number of horizontal rows, N_r = 6 ;
- total number of holes per section, N_h = 2 holes x 6 rows x 5 sections = 60 holes;
- total explosive charge, Q_t = 5 sections x 0,55 kg = 2,8 kg. and 5 x 10 lm = 50 lm of detonating cord.

Dynamite type explosive loads were placed in holes drilled in supporting pillars, ring belt and cuts on the tower body. The explosive charges were connected with detonating cord and initiated with non-electric detonators and connectors. The order of detonation of explosive loads it is presented in the Figure 12.

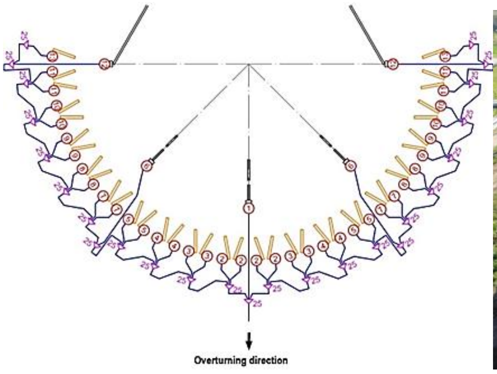


Figure 12. Initiation network

Figure 13. External protection

The total explosive materials consumption at the demolition of the cooling tower was the following :

- explosive: 43,00 kg
- detonating cord: 730 lm
- nonelectric system detonators: 45 pcs.
- nonelectric connectors, delay 25 ms: 25 pcs.

6. RISKS ASSESSMENT

The main outcomes from the risk evaluation specific for the performed work are presented bellow [4 -7, 9].

Throwing of small material under the effect of the explosion at the chimney demolition was diminished by the installation at the level of the detachment cut of means of protection with materials made of welded wire mesh with large mesh, flexible wire mesh with small mesh, and an external protection of geotextile (Figure 13). The external protection covered the area of the explosive charges, exceeding the lower and upper parts of the detachment cut.

The impact of a collapsing structure on the ground may cause seismic effects, the magnitude of which is determined by the energy produced during impact. This energy is proportional to the mass of the building being demolished, the height of its center of gravity, and the properties of the ground on which it falls. cause seismic effects, the magnitude of which is determined by the energy produced during impact. This energy is proportional to the mass of the building being demolished, the height of its center of gravity, and the properties of the ground on which it falls.

The risk assessment showed that for the objective closest to the tower (at a distance limit of 24–74 m), the value of the velocity of seismic waves possible to be generated at the impact of a collapsing structure of the chimney on the ground is 0,70 cm/s—a value lower than 1,10 cm/s, the one chosen as permissible. To reduce the impact on the ground, a damping bed was arranged in the direction of overturning of the tower.

To verify the level of vibration induced in the ground by the impact when construction was demolished, two seismometers were placed at the closest buildings. The results of the measurements confirm that the seismic values induced by the collapse of the cooling tower are lower than the permissible ones of 1.10 cm/s.

The overpressure of the shock wave can generate a piston effect on the air, which can be produced when the tower body descends vertically and propagates outside the tower site at distances of 15-20 m, having high values. To prevent this effect, preparations were made to section the tower body with a combination of vertical and inclined cuts. Also, between the construction of the cooling tower and the objectives to be protected, on 1/2 of the perimeter of the tower, in the area opposite the direction of overturning, a protective berm of earth was set up, with a height of 6–7 m. In addition, a protection made of flexible wire mesh and geo-textile cloth was arranged in the area close to the fence of the properties neighboring the tower.

To reduce *dust pollution*, the surface on which the construction is to fall was sprinkled with water before, during, and after the collapse of the construction.

Figure 14. Secvential view of tower demolition

7. CONCLUSION

A vast number of demolition works using explosives and a high degree of complexity have demonstrated that the blasting approach is an appropriate option in terms of efficiency, quality, and security.

The novelty of the presented demolition work consisted in the solutions for preparing the structure for demolition, such as the use of a combination of vertical and inclinated cuts located at certain heights and having certain lengths, as well as in the solutions identified to minimize the effects of the demolition work—how would be the raising of an earth wave at the tower's limit, at a height equal to the supporting legs, setting up an earth-made bed to absorb the impact in the direction of toppling the tower? All these techniques are discussed in this paper, and based on the blasting concept and risk assessment, successfully completed the demolition by blasting works of the cooling tower construction (Figure 14).

Acknowledgements

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METHODS FOR IDENTIFYING AND ASSESSING RISKS OF OCCUPATIONAL INJURY AND DISEASE - THEIR SUITABILITY FOR ASSESSING EMERGING RISKS

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Abstract: *The integration of digital technologies, including industrial automation, artificial intelligence, advanced robotics, the Internet of Things (IoT), additive manufacturing (3D printing), etc., is radically transforming industrial and organizational work environments. These emerging technologies bring both significant opportunities for efficiency and innovation, but also introduce new and complex risks to worker safety (exposure to electromagnetic radiation, cognitive overload, cyber risks, potential for accidents caused by human-machine interactions, etc.). Effectively identifying, assessing and managing these emerging risks is critical to ensuring a safe, healthy and efficient workplace atmosphere. The purpose of this research, which is based on previous theoretical and empirical studies, was to: identify the most used methods/methodologies/tools for hazard identification, risk analysis and occupational injury and disease risk assessment; the comparative analysis of the selected methods, to highlight their advantages and disadvantages, respectively their limitations. Also, the research sought to examine the effectiveness and suitability of the selected methods for identifying and assessing new risks emerged from the adoption of digital technologies in technological and manufacturing processes. In the context of rapid technological evolution, it is essential to improve and adapt these methods to be as accurate, adaptable and to remain relevant, thus ensuring better protection of the working environment and more effective risk management in an era of production more and more digitized.*

Keywords: *method, risk, emerging risk, risk analysis, safety*

1. INTRODUCTION

The integration of digital technologies (industrial automation, artificial intelligence, advanced robotics, Internet of Things (IoT), additive manufacturing (3D printing), augmented reality (AR) and virtual reality (VR), etc.), radically transforms industrial and organizational work environments. These emerging technologies bring both significant opportunities for efficiency and innovation, but also introduce new and complex risks to worker safety (exposure to electromagnetic radiation, cognitive overload, cyber risks, potential for accidents caused by human-machine interactions, etc.) [1–3].

The assessment of emerging risks identified as a result of the adoption of new digital technologies in organizations requires the application of methods capable of addressing the uncertainties and complexities specific to this domain.

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This research seeks to enhance the existing knowledge in this field by setting the following objectives:

1. Comparative analysis of the most commonly used methods/methodologies/tools for hazard identification, risk analysis and risk assessment related to workplace injury and illness, in order to highlight their advantages and disadvantages, respectively their limitations. The study also aims to analyze the effectiveness and suitability of the selected methods for identifying and assessing new risks emerged from the adoption of digital technologies in technological and manufacturing processes.
2. Development of a set of issues that we recommend for analysis and taking into consideration in order to effectively address the risks associated with the implementation of digital systems.

The research begins by briefly presenting the methodology used to identify and select the methods/methodologies/tools for identifying and evaluating the risks associated with work-related injuries and illnesses, followed by the findings obtained from analyzing the data and the scientific literature on the selected methods. In the last part, we shared our study conclusions along with the existing research constraints in this field.

2. METHODOLOGY

The method by which the identification and selection of methods/methodologies/tools for hazard identification, risk analysis and risk assessment of occupational injury and ill health is carried out is presented in Figure 1:

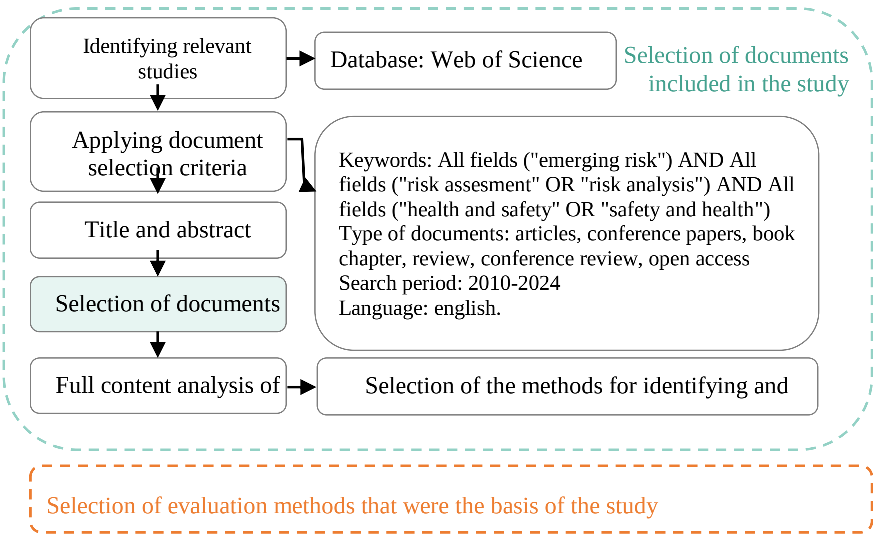

Figure 1. The approach used to select the documents analyzed in the study

3. RESULTS AND DISCUSSION

Risk assessment is an essential process within every organization as it enables the systematic identification and understanding of risks, facilitating informed decision-making and the development of risk management strategies [4, 5].

This process involves a detailed analysis of the working system, the technologies used, the regulatory framework, all operational aspects including business processes. Risk assessment is not only limited to their identification, but also involves a detailed analysis of the impact and probability of each risk. This analysis is essential for prioritizing risks, taking proactive measures and avoiding or reducing the negative impact of risks [4].

A brief presentation of the risk assessment process was made in Figure 2.

In this study, 8 frequently used methods of identification and assessment of occupational injury and disease risks were selected and analyzed: scenario analysis, cause-effect analysis (ISHIKAWA diagram; FISHBONE diagram), analysis of failure modes and effects (FMEA), hazard and operability study (HAZOP), level of protection analysis (LOPA), risk assessment matrix, Bow-Tie analysis and the I.N.C.D.P.M method (developed by the "Alexandru Darabonț" National Research and Development Institute for Labor Protection from Bucharest Romania).

A detailed presentation of the selected evaluation methods was not included, as this analysis, which is based on previous theoretical and empirical studies, focused on identifying the advantages and limitations/constraints of each method, the results obtained being synthesized and presented in Table 1:

Table 1. Methods for the identification and evaluation of risks related to occupational injury and illness – advantages and limitations/constraints

	The advantages of the method	**Limitations/constraints**
Scenario analysis [9, 10]	- qualitative analysis method, but can be adapted to include quantitative elements; - allows the anticipation and management of potential risks, as it is based on the development of hypothetical scenarios, based on different variables and circumstances; - allows the prioritization of risks, by using a structured approach; - enables risk assessment in a dynamic context, given that scenarios can be adapted to reflect various conditions and technological developments; - through the detailed analysis of the various possibilities and consequences, it contributes to the improvement of the decisions taken.	- the process of collecting data, building scenarios and analyzing them is a complex and lengthy process; - incorrect or incomplete input data can lead to erroneous conclusions and affect the quality of the analysis results; - sometimes the ability to predict all risks is limited, given that it is almost impossible to anticipate all possible variables and interactions.

Cause-effect analysis (ISHIKAWA diagram; FISHBONE diagram) [9, 10]	- method of systematic, structured analysis, used to identify the potential causes that contribute to the emergence of a certain risk; - allows the development of effective preventive measures, following the identification of the root causes of the issue/danger.	- the analysis is difficult to manage in the case of complex situations, with multiple interrelated causes; - the analysis focuses on the immediate causes thus, it is possible to neglect the wider context or factors that may contribute to the emergence of risks; - the analysis focuses on identifying causes but does not provide direct information on the impact or likelihood of identified risks; thus, it is necessary to use other complementary methods to evaluate these aspects.
Hazard and operability study (HAZOP) [11–13]	- method of systematic, qualitative, structured analysis, used to identify potential hazards and assess injury risks; - involves teams of experts from different fields; - focuses on identifying hazards before they manifest themselves in incidents or events; - allows the identification of potential operational hazards (e.g. that may arise due to abnormal operating conditions) and the assessment of the impact of deviations from design specifications; - allows adaptation to the specifics of each process.	- the quality of the HAZOP analysis is directly proportional to the level of experience and knowledge of the team members; - assessment of the severity, frequency and detectability of risks is often subjective and may vary between team members; - focuses on individual failure modes without adequately considering the complex interactions between them.
Bow-Tie Analysis [9, 14]	- graphic, systematic analysis method used for risk management, for analyzing the effectiveness of checks in relation to different risks; - allows a thorough analysis of the factors that can contribute to the occurrence of a critical event and the effects/ consequences that this event can have, thus facilitating the implementation of measures to prevent and reduce the consequences; - allows adaptation to the specifics and particular needs of each organization.	- is appropriate for assessing emerging risks associated with new digital technologies, but to be effective it must be used in conjunction with other risk assessment methods and supported by expertise and up-to-date data; - creating a Bow-Tie chart is a complex process and requires specialized expertise; - the method is effective for risk prioritization due to its logical structure and the ability to identify the causes, effects and control measures associated with each risk; - analysis is not very adaptable in dynamic risk management;

		- the analysis focuses on single critical events and is not suitable for risk analysis involving complex interactions between events; - the quality and usefulness of Bow-Tie analysis is dependent on the quality of the input data. Incomplete or inaccurate information can lead to erroneous conclusions and the implementation of ineffective control measures.
The I.N.C.D.P.M method (developed by the National Research-Development Institute for Labor Protection "Alexandru Darabonț" from Bucharest, Romania) [10, 15–17]	- systematic, standardized analysis method used to identify and evaluate risks associated with occupational injuries and illnesses; - in order to take into account the evolution of risks over time, it is necessary to periodically update and continuously monitor the work system; thus, adjustments can be made depending on the evolution of processes and the appearance of new risks or changes to existing ones.	- the results obtained may be influenced by the individual perceptions and experiences of those carrying out the assessment, which may lead to subjective interpretations and variations in identifying and evaluating risks; - the lack of accurate and up-to-date data may affect the accuracy and relevance of the risk assessment; - in order for the method to be suitable for the specifics of different processes, it is necessary to adjust the risk assessment criteria and procedures according to the specifics of each operational process; - for the method to be effective in addressing complex interactions between events, careful and well-supported implementation (resources, accurate and detailed data, objectivity in the evaluation process, etc.) is required.
Failure Modes and Effects Analysis (FMEA) [11, 18]	- systematic, semi-quantitative analysis method used to detect potential failure modes within a system, product or process before they occur in practice; - allows the identification of risks that could affect the safety of operators; - by calculating the RPN (Risk Priority Number), it helps to prioritize risks (according to severity, frequency of risks) and focus on the most critical aspects;	- is effective in identifying known risks, but may not be as effective in detecting emerging risks, especially in the case of new technologies; - assessment of severity, frequency of risks is often subjective and may vary between team members. This can lead to differences in the calculation of RPN and implicitly, in the prioritization of risks;

	- allows detailed assessment of the impact of these risks (causes and consequences of failure).	- focuses on individual failure modes without adequately considering the complex interactions between them.
Analysis of protection levels (LOPA) [10–12]	- method of systematic, semi-quantitative analysis, used to assess occupational risks and determine the effectiveness of protective measures in a system or process; - it allows the prioritization of safety measures necessary to achieve the acceptable level of risk; - enables an integrated, comprehensive approach to risk analysis by using it in combination with other risk analysis methods; - allows adaptation to the specifics and particular needs of each organization.	- incorrect or incomplete input data can affect the quality of the analysis results; - calculating the probabilities and effectiveness of protective measures can be complex, requiring a high level of expertise and knowledge; - assessing the severity and likelihood of risks is often subjective and may vary between team members; - it is less effective in addressing global risks; - does not provide an adequate approach to human and organizational factors.
Risk assessment matrix [4, 9, 12]	- structured, systematic, quantitative and reproducible analysis method in risk management; - allows risks to be prioritized according to criteria such as likelihood of occurrence and potential effects on the safety and health of workers; - the matrix can be used for risk monitoring and periodic updating of the risk assessment according to changes in the work system.	- it is not flexible or detailed enough to enable the management of complex risks or to address the complex interactions between different risks; - the method is subjective, the assessment of probability and impact being influenced by the individual perceptions and experiences of those involved in the assessment process; - the lack of accurate and up-to-date data and information can influence the effectiveness of the assessment.

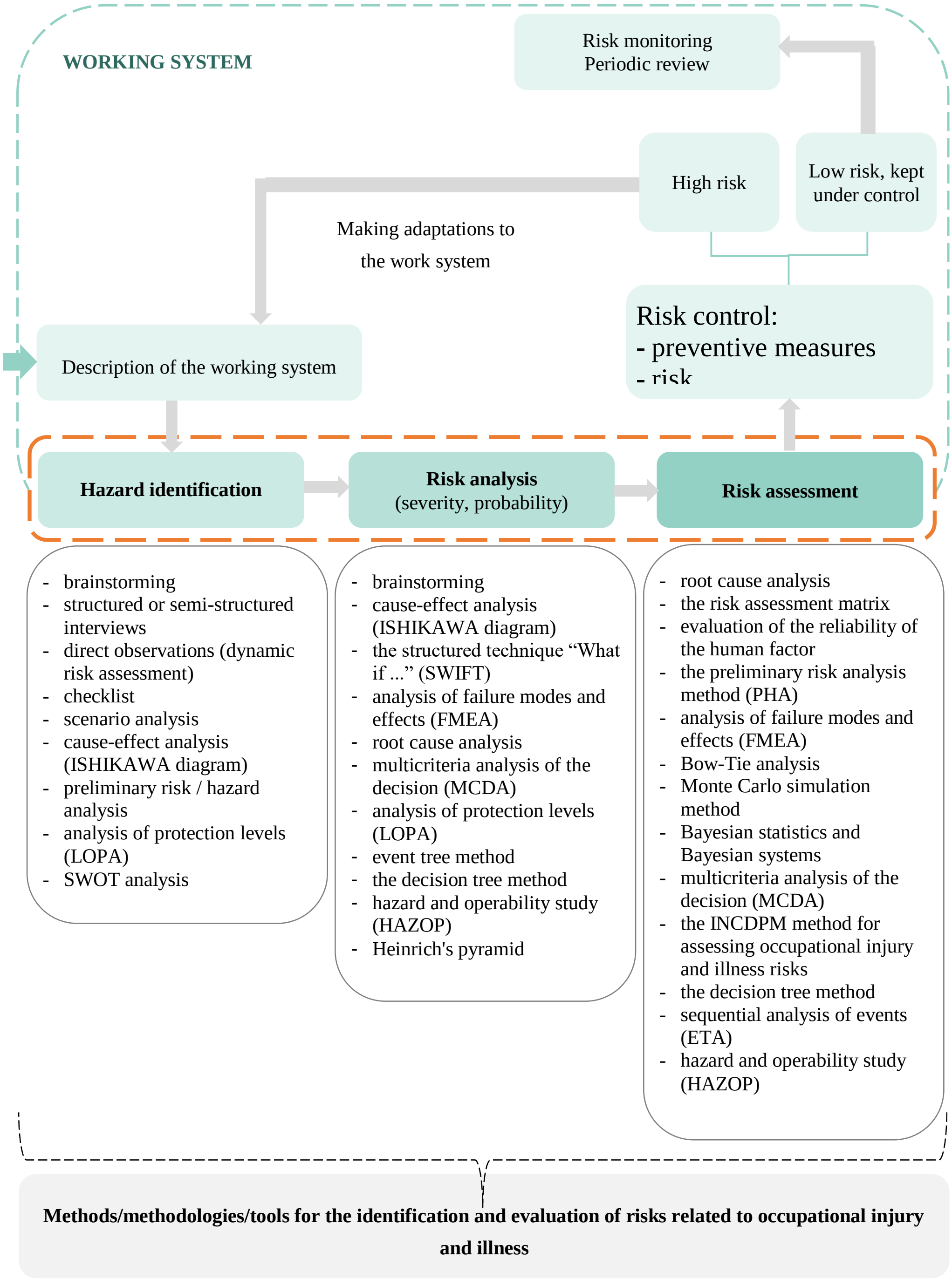

Figure 2. Synthesis of the risk assessment process [6–8]

Table 2 summarizes the findings derived from comparing certain aspects regarding the selected methods, precisely to have a clearer perspective on the advantages and limitations/constraints of the analyzed methods:

Table 2. Methods for the identification and evaluation of risks related to occupational injury and illness – comparative analysis [4, 9, 18, 10–17]

	Qualitative analysis method			Semi-qualitative analysis		Semi-quantitative analysis		Quantitative analysis method
The method of identifying and evaluating risks / **Aspects analyzed**	**Scenario analysis**	**Ishikawa /Fishbone**	**HAZOP**	**Bow-Tie**	**INCDPM**	**FMEA**	**LOPA**	**Risk matrix**
It is suitable for assessing emerging risks ?	YES	YES	YES	YES	NO	NO	YES	YES
It involves a multidisciplinary analysis team ?	YES	YES	YES	YES	YES	YES	YES	YES
Take into account the evolution of risks over time ?	YES	NO	NO	NO	YES	NO	NO	YES
It is a subjective method ?	YES	YES	YES	NO	YES	YES	YES	YES
Allows risk prioritization ?	YES	NO	YES	YES	YES	YES	YES	YES
It allows adaptation to the specifics of different processes ?	YES	YES	YES	YES	YES	YES	YES	YES
It addresses the complex interactions between events ?	YES	NO	NO	NO	YES	NO	NO	NO

As can be seen, each of these methods has its own advantages and limitations and may be more suitable depending on the specific context of the organization, the complexity and the specificity of the emerging risks associated with the integration of digital technologies.

These "classical" methods of identifying and assessing occupational injury and disease risks, developed in the 20th century, focused on the traditional physical, chemical, biological, ergonomic risks associated with workplaces in industry, construction, agriculture and other similar sectors. These methods have been designed to address obvious and tangible risks that can lead to occupational accidents or illnesses, such as exposure to hazardous substances, poor working conditions or unsafe equipment. With the rapid technological evolution and the integration of digital solutions within organizations, new types of risks have emerged that do not fit into traditional categories.

Therefore, in order to address the complexity of the risks associated with digital systems, and to carry out a comprehensive and effective evaluation of the risks of occupational injury and illness, a systematic and structured approach that takes into account a number of critical issues is essential [4]:

- developing within organizations a positive safety culture, supported by management commitment, active worker involvement and continuous improvement efforts – an aspect that is essential for improving worker safety [4, 19];
- analysis of dependencies and interactions between all components of the work system: human factors/executor, equipment, technologies, technological processes (manufacturing processes, maintenance processes, emergency response plans, etc.), environmental factors, management factors, etc., precisely to identify the specific risks associated with each technology used [4];
- adapting the predefined lists of risks related to occupational injury and illness, by including the emerging, specific risks associated with new digital technologies (probability of cyber attacks, impact on sensitive data, consequences on the well-being of employees, including both mental and physical aspects, etc.). These risks are usually complex and interconnected, and for this reason, a multifactorial and multidisciplinary approach is essential precisely in order to correctly identify and assess them;
- developing risk scenarios specific to new digital technologies and assessing their impact on occupational safety and health;
- applying assessment methodologies that address proactive risk management, thus improving worker safety by reducing the likelihood of events occurring;
- the implementation of continuous risk monitoring programs, assessing how effective the implemented control measures are and periodically updating the risk assessment, as new risks are identified or new technologies are integrated;
- the integration of digital technologies (artificial intelligence, big data, etc.) in the risk assessment process due to the advantages they imply, for example: the possibility of collecting and analyzing data in real time; the possibility of identifying trends; the possibility of constant monitoring of working conditions and safety parameters, thus providing real-time alerts about potential dangers; the possibility of rapid generation of personalized reports, thus facilitating the interpretation and communication of identified risks to all levels of the organization, etc.

As can be seen from Table 2, the analyzed methods can be used to address the emerging risks associated with the integration of digital solutions, but under the conditions of their adaptation to remain relevant, to be more flexible, to include a holistic approach and to be based on an interdisciplinary collaboration, to maintain a safe and healthy work environment in the era of digital technology [20].

5. CONCLUSIONS

This study's contribution consists in:

1. Carrying out a comparative analysis of 8 selected methods for the identification and evaluation of risks related to occupational injury and illness. By comparing these methods, the study identifies the advantages and limitations/constraints of each, helping practitioners to choose the most appropriate methods for their specific needs.
2. Proposing a set of issues that we recommend for analysis and taking into consideration in order to address the complexity of the risks associated with the integration of digital systems.

In order to assure a cohesive and efficient approach to risk assessment, including emerging risks resulting from the adoption of new digital technologies, it is essential to develop and apply a methodology that is adapted to the organizational context, the complexity of the integrated technologies and the nature of the identified risks. In many cases, a combined approach, i.e. using several methods in parallel, can ensure a more proactive, comprehensive and robust approach to risk management [9].

Limitations of the research:

The present study included the conclusions obtained after analyzing a limited number of methods for the identification and evaluation of risks related to occupational injury and illness. It is necessary to analyze a greater number of methods, precisely to ensure an adequate approach to the emerging risks generated by new digital technologies.

We recommend further studies to update / adapt risk assessment procedures and tools to include emerging risks generated by digitization. An integrated approach combining cyber security expertise, risk management and occupational health is essential for this adaptation.

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CASE STUDY ON SPECTRAL CHARACTERISTICS OF ROAD TRAFFIC NOISE

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Abstract: *The ambient noise has a major effect on health by creating a discomfort for individuals exposed to it, becoming a form of environmental pollution that produces symptoms associated with stress, fatigue, dizziness, irritability, sleep disorders, and even tachycardia.*
The objective of this paper is to provide an introduction to the methodology of determining ambient noise, by identifying spectral characteristics in order to adopt optimal measures to reduce unwanted effects and improve the comfort level of residents near traffic arteries. Every ambient noise determination is a challenge for specialists who need to manage a multitude of variables such as accurate identification of noise source(s), their representative operating conditions, adjusting measurement periods to meteorological conditions (which cannot be controlled by the operator), including wind direction/speed, atmospheric turbidity and the possibility of precipitation. The paper outlines provisions regarding the equipment used for acoustic measurements, measurement principles, source operating conditions, meteorological conditions, measurement procedures and result evaluation.. This study analyses the noise level generated by road traffic over a monitoring period of 4 months at the main intersections in the East area of the Jiu Valley. It presents the spectral characteristics of sound pollution level created by road traffic, identifying dominant frequencies and comparing them with legal limits to quantify the discomfort experienced by residents living near traffic arteries. Implementing effective measures to reduce the noise impact on residents requires spectral analysis of noise, to identify frequencies likely to cause discomfort and select optimal solutions/materials based on those characteristics.

Key words: *ambient noise, urban noise, road traffic, noise pollution*

1 INTRODUCTION

Traffic arteries placed near residential areas and the increase in traffic levels have become the main source of noise in residential zones. The growing exposure of population to ambient noise in residential areas has become a widespread issue affecting the quality of life.

Determining the level of ambient noise is a complex activity, with a large number of variable parameters that must be considered when planning and conducting measurements. Each determination is influenced by the number of vehicles passing through the area, their speed and mass, the quality of road surface, and weather

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conditions. Meteorological parameters that influence sound propagation include wind speed, wind direction, relative humidity, temperature and the presence of precipitation, all of which generate a considerable source of measurement uncertainty [1].

With urban development, ambient noise has become an omnipresent component of life, with the main causes of urban noise pollution being:

- Noise produced by vehicles (cars, buses, motorcycles, ambulances);
- Noise from rail traffic;
- Noise from temporary construction sites;
- Noise from economic and entertainment activities (HORECA), such as outdoor terraces, restaurants, and concerts;
- Noise from industrial activities conducted in or near urban areas (loaders, forklifts, compressors, generators, etc.).

The presence of a multitude of noise sources generating sound pollution directly affects the neighborhoods, exposing a varying number of residents. Road traffic, being omnipresent in all urban agglomerations, thus becomes the main source of noise with a major impact on the activities of residents, affecting most of them.

Noise pollution generated by road traffic is exacerbated by the condition of road surfaces, technical condition of vehicles and their speed. Additionally, the intensity of road traffic, the quality of the road, and the type of vehicles (light/heavy) passing through the area play an important role.

The increase in the number of vehicles has led to an intensification of the noise level generated in the ambient environment, primarily affecting neighborhoods located at a relatively short distance from these sources. Using the SR 10009:2017 standard, locations susceptible to excessive exposure to noise levels, above the maximum permissible values were identified, and spectrograms of noise levels were also created where it was considered necessary to apply noise reduction measures.

2 PARTICULARITIES OF THE DETERMINATION OF AMBIENT NOISE GENERATED BY ROAD TRAFFIC

Ambient noise generated by road traffic is a major environmental concern, especially in urban areas. Accurately determining this noise is essential for evaluating its impact on human health and developing effective noise reduction strategies [2,3]. This involves various measurement equipment, analysis methods, and an understanding of influencing factors.

2.1 Measurement Equipment

Sound Level Meters:

- The primary instruments for measuring road traffic noise. They analyze sound pressure levels and display the level in decibels (dB).
- Sound level meters filter noise using frequency weighting on the A-weighting curve, which mimics the human ear's response to different frequencies, making it the standard for measuring ambient noise.

Fixed Noise Monitoring Stations:

- These are fixed or portable units installed at specific locations to continuously monitor noise levels over long periods.

- They are equipped with sound level meters and data recorders to capture noise variations and provide long-term data for analysis.

Mobile Noise Monitoring Stations:

- Conducted using vehicles equipped with noise measurement instruments, these studies cover larger areas and provide spatial distribution data of road traffic noise.

- Used for mapping noise levels in different parts of a city.

2.2. Analysis Methods

Statistical Analysis:

- Involves calculating noise statistical indices such as L10, L50, and L90, which represent noise levels exceeded for 10%, 50%, and 90% of the time, respectively.

- Leq (Equivalent Continuous Sound Level) is a primary indicator representing the average noise level over a specified period.

Spectral Analysis:

- Breaks down noise into its frequency components to identify dominant frequencies and their sources.

- Fast Fourier Transform (FFT) is commonly used for this purpose, providing detailed frequency spectra of the noise.

Temporal Analysis:

- Examines how noise levels vary over time, considering factors like traffic flow, peak hours, and weather conditions.

- Helps understand patterns and predict noise levels at different times of the day.

2.3. Key Factors Influencing Noise Pollution Levels

Traffic Volume and Composition:

- Higher traffic volumes typically lead to higher noise levels. Traffic composition (cars, trucks, motorcycles) also affects noise characteristics.

- Heavy vehicles generate more low-frequency noise compared to lighter vehicles.

Vehicle Speed:

- Noise levels increase with vehicle speed due to higher engine, tire, and aerodynamic noise.

- Speed limits and traffic calming measures can significantly influence ambient noise levels.

Road Surface and Condition:

- Different road surfaces (asphalt, concrete, cobblestone) have varying impacts on noise generation, especially from tire-road interaction.

- Poorly maintained roads with potholes and cracks can increase noise levels.

Topography and Urban Structures:

- Buildings, barriers, and vegetation can reflect, absorb, or block noise, affecting the overall noise level in an area.

-Narrow streets flanked by tall buildings can amplify noise due to reflections.

3 CASE STUDY

In the research activities conducted by INCD INSEMEX Petroşani, a series of noise measurements were carried out, for road traffic noise in the eastern area of the Jiu Valley. The measurements were conducted in accordance with national legislation. Monitoring points were placed at main intersections (Figure 1), especially in areas crossed by national roads (DN 66), county roads (DJ 709K), and boulevards (1 Decembrie 1918)[4,5].

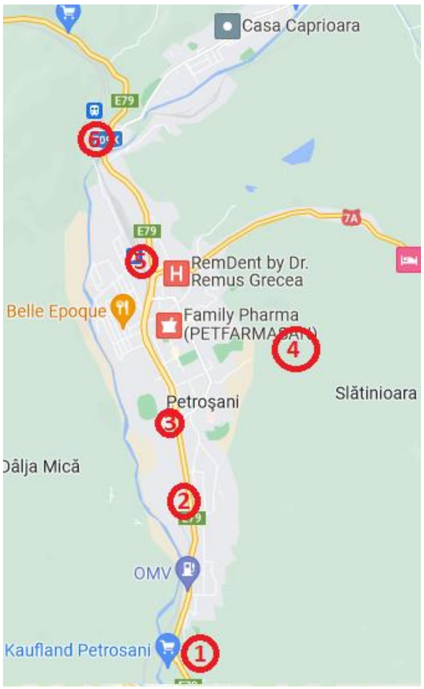

Figure 1. Location of monitoring points

Figure. 2. Location of monitoring points (points 6 and 5)

Figure. 3. Location of monitoring points (points 3, 4 and 2)

Table 1 shows the noise level values for each monitoring point (LAeq dB(A)).

Table 1. The values obtained during the monitoring period

Nr. crt	Locație	February	March	April	May
1	Roundabout General Trans	70.2	66.6	71.3	71.4
2	Livezeni street	64.2	71.2	70.1	69.3
3	Airplane roundabout	69.6	68.9	69.8	69.3
4	University	52.3	51.8	53.6	52.1
5	Piața Victoriei roundabout	59.9	70.1	68.9	65.3
6	Rotary Petrila	56.3	67.5	66.3	68.9

In order to quantify noise level, the obtained values were compared to the values specified in SR 10009:2017 for determining the noise level at the limit of functional premises [6,7].

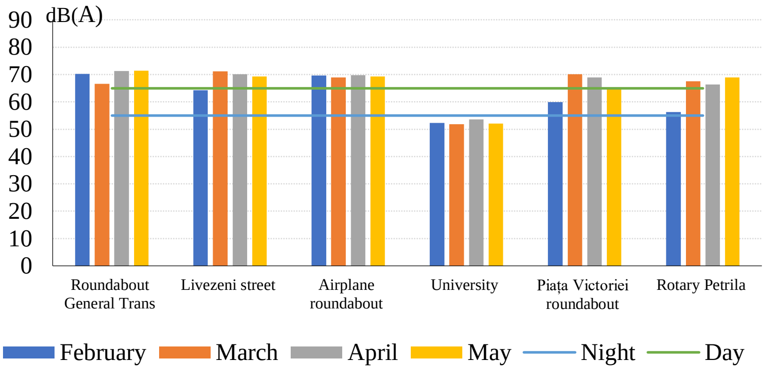

Figure 4. Graphical representation of the results obtained and the limits established by the legislation in force for the respective night and day period.

Understanding the spectral characteristics of road traffic noise is essential for developing effective noise control measures [8]. By analyzing the frequency content of traffic noise, we can better identify its sources and impact, leading to more targeted and efficient mitigation strategies. Next, we will present the spectral analysis from a representative monitoring point, located approximately 5 meters from the facade of a residential building.

Table 2. Spectral analysis of values obtained during the monitoring period for point 2

Frequency [Hz]	February	March	April	May
	LZeq [dB]	Lzeq [dB]	Lzeq [dB]	Lzeq [dB]
16 Hz	61.4	69.4	64.5	71.6
31.5 Hz	69.5	81. 0	70.6	82.8
63 Hz	70.5	74.5	77.4	76.5
125 Hz	65.4	67.9	72.3	68.1

Frequency [Hz]	February	March	April	May
	LZeq [dB]	Lzeq [dB]	Lzeq [dB]	Lzeq [dB]
250 Hz	61.3	66.8	68.5	64.5
500 Hz	59.5	66.1	63.7	64.5
1 kHz	60.4	66.7	64.4	65.4
2 kHz	57.5	66.4	62.7	65.5
4 kHz	54.7	60.7	61.3	60.2
8 kHz	52.6	49.0	59.2	49.6
16 kHz	45.2	31.3	51.4	35.4
CZ	61	69	66	68
Laeq	64.2	71.2	70.1	69.3

Notes:

- One-octave analysis
- CZ Noise Curves are used to describe the human perception of noise at different intensity and frequency levels. They help assess the impact of noise on human comfort and health. Noise curves are expressed in decibel (dB) units, which measure noise intensity. The noise level is often weighted to reflect the human ear's sensitivity to different frequencies, using weighting filters such as dBA. The human ear perceives noises differently at various frequencies. Therefore, noise curves are presented according to the sound frequency (Hz). For example, low-frequency noises may be less disturbing at the same dB level compared to high-frequency noises.

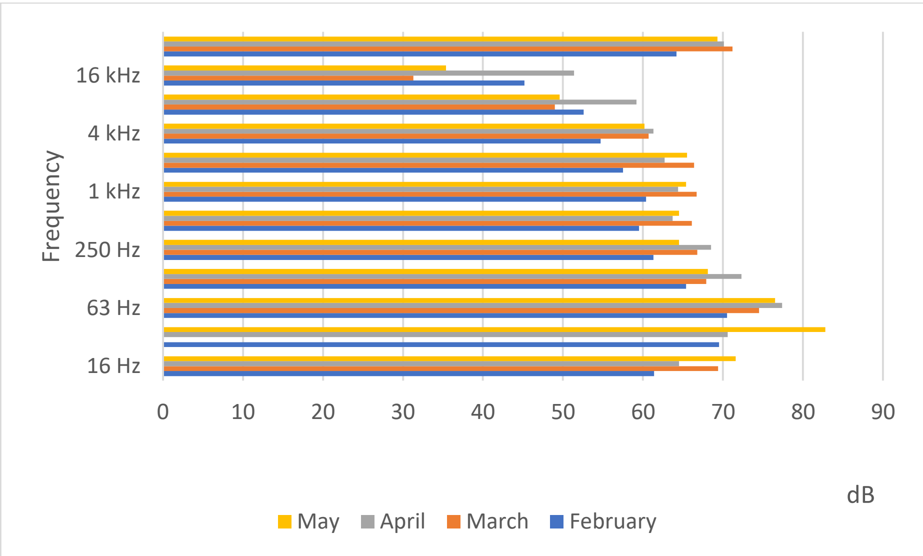

Figure 5. Graphic representation of the results obtained in monitoring point no. 2.

Exposure to noise is a health risk factor. It has been demonstrated that low-intensity but disturbing noises that enter homes due to external traffic or adjacent rooms, through their continuous action, both day and night, have an irritating effect on the human body.

Sleep disturbances caused by noise can contribute to cardiovascular diseases, neuroses, states of fear, and aggression. Noise can also create difficulties in the learning process, especially in schools, where a very low noise level is essential.

Being constantly surrounded by sounds, in most cases, our activities can continue by ignoring the noise. However, as the noise level increases, it becomes a polluting factor in the living and working environment.

The influence of noise on the human body depends on several factors, such as:

- Type of noise: intensity, frequency, duration of exposure, continuous or intermittent nature;
- Individual characteristics: age, activity, state of fatigue, habituation, mood, sensitivity, culture, education;
- Environmental factors: space size, architectural structure, etc.

In the European Union, nearly 40% of the population is exposed to road traffic noise levels exceeding 55 dB(A) as an A-weighted sound pressure level during the day and 20% of the population is exposed to levels exceeding 65 dB(A). Considering noise from all transport sources, it is found that almost half of the EU citizens live in areas where acoustic comfort is not ensured.

For the nighttime period, it is estimated that over 30% of the population is exposed to noise levels exceeding 55 dB(A), thus disturbing sleep.

The quality of environmental factors, especially urban noise, influences the population's health. For this reason, monitoring the noise levels outside buildings and evaluating the health impact are essential for prophylactic activities.

According to the provisions of Order MS 119/2014, chapter I, article 16 :

- During the daytime, the equivalent continuous A-weighted sound pressure level (AeqT), measured outside the dwelling according to the SR ISO 1996/2-08 standard, at 1.5 meters above ground level, should not exceed 55 dB and the CZ 50 noise curve.
- During the nighttime, between 23:00 and 7:00, the equivalent continuous A-weighted sound pressure level (LAeqT), measured outside the dwelling according to the SR ISO 1996/2-18 standard, at 1.5 meters above ground level, should not exceed 45 dB and the CZ 40 noise curve.

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4 CONCLUSIONS

Following the analysis of the noise levels generated by road traffic, the following conclusions were drawn:

The analysis of noise measurements conducted in high-traffic areas showed that noise exposure levels ranged between 51.8 - 72.3 dB(A), with exceedances of the 65 dB(A) limit in most monitoring points over the four-month monitoring period.

Spectrogram analysis revealed that the exceedances occur in the low and mid-frequency bands, which are considered dangerous, necesitating the implementation of technical and organizational measures to reduce the health impact on residents. Road traffic noise predominantly falls within the low and mid-frequency spectrum, particularly between 50 Hz and 1000 Hz, generated by vehicle engines, braking, and tire-road contact. Less pronounced than the low and mid frequencies, high frequencies (over 1000 Hz) are present in road traffic noise, mainly produced by horns and brakes.

Low and mid frequencies, predominant in traffic noise, can easily penetrate walls and windows, affecting the acoustic comfort inside buildings and having adverse health effects such as stress, sleep disturbances, and cardiovascular diseases. High-frequency noises can be perceived as more disturbing and can contribute to discomfort and irritation.

Given that reducing noise generated by road traffic is a systemic issue, the goal of noise reduction is to achieve acoustic comfort at an acceptable cost. The primary variables of the system are acoustic characteristics and cost. To have a system for reducing population exposure to noise generated by road traffic, it is necessary to adopt technical and organizational measures such as asphalting roads, introducing one-way streets on adjacent roads, promoting electric vehicles, planting ornamental shrubs near traffic arteries, and installing soundproof barriers near noisy traffic arteries.

In conclusion, road traffic is the main source of noise pollution in most cities, not just in large urban agglomerations, which are subject to monitoring under the provisions of LAW No. 121 of July 3, 2019, regarding the evaluation and management of ambient noise. Measures to reduce the level of exposure to ambient noise should be applied uniformly to all localities affected by road traffic, not just the large urban agglomerations subject to monitoring through noise maps created under Law 121/2019.

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CHEMICAL CHARACTERIZATION OF INDUSTRIAL WASTE - CASE STUDY

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Abstract: *Many consumer items contain recycled components as part of a circular economy; however, the chemical composition of recycled products is typically unknown. The composition of waste materials has a significant impact on environmental emissions related to waste treatment, recycling, and disposal. It may also have a substantial impact on the life-cycle assessment of waste management solutions. However, the influence of the waste composition is rarely considered in evaluations, and trash life cycle assessment usually rely on inaccurate secondary source data. To determine the overall composition of a waste combination, the components are separated, individually tested for chemical composition, and the results are combined. In this paper, three samples of recycled materials underwent an ATR mode FTIR spectrometer screening study. X-ray fluorescence (XRF) was used to analyze the sample composition in terms of the identification of metals and metal oxides. The chemical compositions of the samples were found by means of a spectral library. Using high-throughput hazard and exposure data, the results were clustered to identify groups of compounds that may be linked to unique chemical sources. These substances were then prioritized for further research. Although incidence by itself does not always imply hazard, these findings can assist in identifying overlooked pathways of exposure in exposure assessments or in enhancing existing models.*

Key words: *FTIR, XRF, compounds, chemical composition, waste.*

1 INTRODUCTION

One of the most challenging environmental tasks for scientists is undoubtedly managing and disposing of industrial solid waste [1]. Industrial waste management is a critical component of sustainable industrial practices and environmental stewardship. As industries grow and technology advances, the volume and complexity of industrial waste increase, necessitating more sophisticated and effective waste management strategies. Effective industrial waste management ensures that industrial operations are conducted in a manner that minimizes their environmental impact, protects public health, and complies with regulatory requirements.

Improper disposal of industrial waste can lead to significant environmental degradation. Contaminants from industrial waste can pollute air, water, and soil, causing long-term damage to ecosystems and biodiversity. Proper waste management

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practices help mitigate these risks by ensuring safe and environmentally sound disposal methods.

In terms of impact on human health, industrial debris often contains hazardous substances that can pose serious health risks to humans. Proper management reduces the potential for exposure to toxic chemicals, heavy metals, and other dangerous materials, thereby safeguarding the health of workers and the surrounding communities [2, 3].

Identifying the chemical composition of industrial debris or residues is a fundamental aspect of effective waste management. Understanding the precise nature of industrial waste allows for assessing the potential environmental and health risks associated, being crucial information for developing mitigation strategies. Also, it ensures that the appropriate disposal techniques are used, preventing environmental contamination and health hazards. By identifying the specific pollutants present in industrial waste, industries can implement targeted pollution control measures. This can include the installation of specialized filtration systems or the use of neutralizing agents to treat toxic substances, contributing to pollution control [4]. Also, identifying valuable components within industrial waste enables their recovery and recycling. This not only reduces the amount of waste that needs to be disposed of but also provides a source of raw materials for further industrial use, promoting resource efficiency and sustainability.

Understanding the waste composition can provide insights into the industrial processes that generate it. This can lead to improvements in process efficiency, reduction in waste generation, and innovation in waste minimization techniques.

In the past, analytical methods differed in that the main interest focused on examining the impact of gaseous emissions on the environment, as well as on soil and water contamination. Later, the focus shifted towards the interest in the waste material itself, since it serves as the origin of future emissions. The governments responded to the environmental impact and the economic implications by implementing legislation for the management of waste products. During the last decades, waste management emerged as a significant industrial sector in countries with a high environmental consciousness and adequate standards.

The development of suitable analytical instruments is a general concern at both the national and European levels, concerning the extensive array of current research topics in waste management. Waste materials present an analytical challenge because their composition and structure are highly variable, which is in direct opposition to the fundamental principles of natural order. The discussion on the reliability and utility of appropriate methods has been prompted by the necessity for environmental compliance and the implementation of limit values by national regulations [3].

Among the various analytical techniques available, Fourier Transform Infrared (FTIR) spectroscopy has emerged as a powerful and versatile tool in the identification and quantification of chemical substances. FTIR spectroscopy leverages the principle of infrared absorption, which involves the production of a distinctive spectral imprint by molecular vibrations. This fingerprint can be used to identify and analyze compounds.

One of the foremost advantages of FTIR spectroscopy is its rapid and non-destructive nature, allowing for real-time analysis without altering the sample. This is particularly beneficial in industrial settings where continuous monitoring and quick decision-making are critical. Furthermore, FTIR can be applied to a wide range of sample types, including solids, liquids, and gases, making it an invaluable tool across diverse industries such as pharmaceuticals, petrochemicals, and environmental science.

The ability of FTIR to provide detailed molecular information through its high-resolution spectra is another significant benefit. It enables the detection of both major and minor components in complex mixtures, enhancing the accuracy and reliability of chemical analyses. This capability is crucial in industrial waste management, where the identification of potentially hazardous substances and the assessment of waste composition are essential for devising appropriate treatment and disposal methods. This is complemented by the development of sophisticated software and chemometric techniques, which facilitate the interpretation of spectral data and the automation of the analysis process. In addition to its analytical capabilities, FTIR spectroscopy is also recognized for its cost-effectiveness. The technique requires minimal sample preparation and can be conducted with relatively low operational costs compared to other analytical methods such as chromatography or mass spectrometry.

This paper aimed to focus on relevant analytical questions and demonstrate the broad applicability of FTIR spectroscopy in waste management for obtaining information on the state of organic matter for process and product control as well as identifying the origin of the waste. Three samples of industrial waste (one liquid waste and two solid waste) were taken and delivered by the beneficiary to the Laboratory for Physico-Chemical Analysis within INSEMEX, to identify the chemical composition and establish their nature. The XRF analysis provided valuable insights into metal and oxide content in waste samples, contributing to a more accurate identification of their origin and nature.

2 DETERMINATION METHOD

Fourier Transform Infrared Spectrometry (FT-IR) is a non-destructive technique that involves low analytical costs and fast responses. These features make FT-IR spectrometry one of the most widely used analysis techniques in physico-chemical analysis laboratories. The advantages of this technique have been brought to specialists' attention and the problem addressed is very broad [5, 6].

Spectrometry is used both as a qualitative method for identifying the presence of a substance in a solution, as well as a quantitative method for identifying the concentration of a substance in a solution. The method can also be used to determine the equilibrium constant of a solution.

The IR range of the electromagnetic wave spectrum contains radiation with wavelengths ranging from 0.8 $\mu m \leq \lambda \leq 1000$ μm. This range can be into three sub-domains: near-infrared (0.8 $\mu m \leq \lambda \leq 2{,}5 \mu m$) and far infrared (over $\lambda = 25$ μm).

In most laboratories, Fourier Transform Infrared Molecular Absorption Spectrometry and Fourier Transform Raman Spectrometry are used as complementary techniques, since each of them exhibits certain aspects for a given sample [7].

The use of X-ray fluorescence analysis (XRF) has the advantages of being multi-elemental, non-destructive, fast, with good accuracy and precision characteristics. Therefore, XRF is a fast and accurate method compared to other multi-elemental analytical techniques. X-ray diffraction (XRD), which is a powerful non-destructive technique that provides information about the structural characteristics of samples at the atomic level, was used to analyze the sample composition in terms of the identification of metals and metal oxides [8].

X-ray Fluorescence (XRF) is a powerful analytical technique used to determine the chemical composition of various sample types, including solids, liquids, slurries, and loose powders. XRF uses X-rays to excite electrons in the atoms of the sample material. These excited electrons emit secondary X-rays, which are characteristic of the elements present in the material. The intensity of the emitted X-rays provides information about the chemical composition of the sample. The information depth in XRF analysis depends on the energy of the element of interest and the sample type, ranging from micrometers to centimeters. For low-energy elements, the quality of the sample surface becomes crucial [9, 10].

XRF can be non-destructive when analyzing samples without any prior preparation, using low-power benchtop instruments. However, for accurate results, sample preparation is recommended, in this way making XRF less non-destructive. There are many advantages of using XRF, from determining chemical composition across a wide range of elements to the applicability on solids, liquids, coating, and layers, and to permitting rapid screening (semi-quantitative analysis).

3 APPARATUS

For the identification of chemical composition, three industrial waste samples were received from the beneficiary and were analyzed by infrared spectrometry method, using a Nicolet IS50 FT-IR type equipment, made by ThermoScientific. The equipment integrates an ATR (Attenuated total reflectance) module with diamond crystal, with a range of 4000 – 400 cm^{-1} (Figure 1a).

Infrared absorption spectra were recorded at a resolution of 4 cm-1, using the ATR analysis technique, as follows:

• Attenuation of total reflection, performed directly on the combustion residue samples - non-destructive analysis;

• Attenuation of total reflection, performed on n-hexane extract, with background read on the solvent.

To identify the contaminants or compounds found in very low concentrations, the sample was subjected to an extraction operation using solvent (n-hexane), at room temperature.

a)

b)

Figure 1. a) Nicolet IS50 Infrared Spectrometer equipment, with ATR module with diamond crystal ; **b)** RIGAKU Supermini 200 Spectrometer

The experimental data obtained was evaluated using the OMNIC software (Thermo Nicolet Corporation), as well as the dedicated libraries containing more than 40.000 IR spectrograms (ThermoScientific, 2013).

The X-ray Spectrometry method is widely used for the qualitative and quantitative determination of the elemental chemical composition of a sample, especially for inorganic substances (minerals, ceramics, metals, soils, etc.) - mainly in industry. This is based on the fact that the wavelength of X-radiation is of the same order of magnitude as the distances between the nodes of crystal lattices (atomic, metallic, ionic, or molecular) and, as a consequence of diffraction and interference, peaks in the intensity of emerging rays occur at certain angles. Analyzing complex matrix materials with a wide range of light and heavy elements, from trace to high concentration levels, is this instrument's core competency. With its high powered (200 W) X-ray tube, Rigaku Supermini200 (Figure 1,b) delivers high XRF sensitivity for light elements with superior spectral resolution for resolving line overlaps in complex matrices without the need for complicated mathematical peak deconvolution.

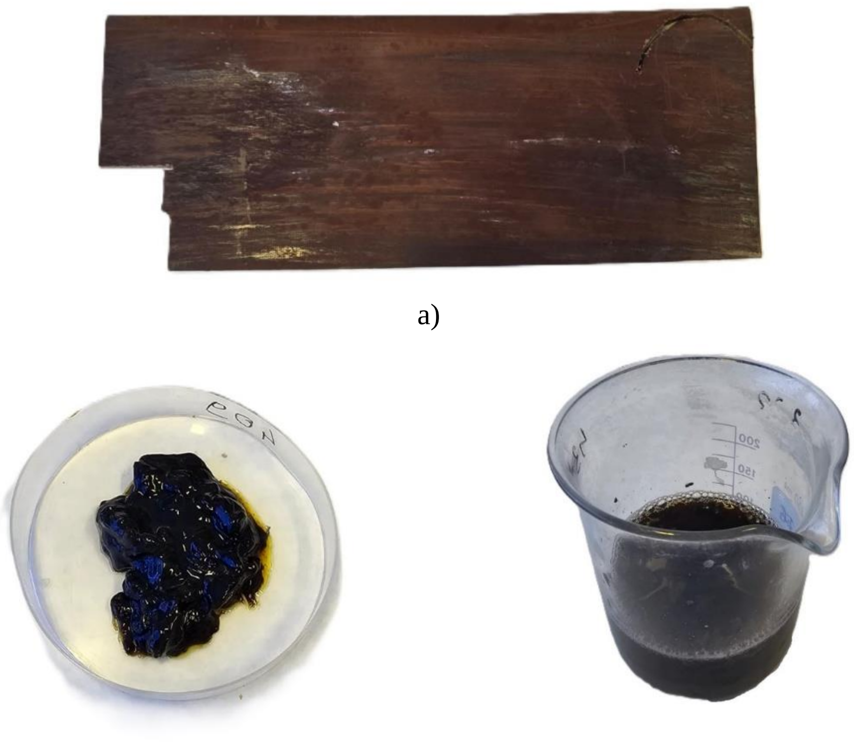
Analyzing low concentration levels of light elements (F, Na, Mg, Ca, Si, Al, and P) is easy.

4 RESULTS AND DISCUSSIONS

For this paper, three waste samples were analyzed, one liquid and two solids. All samples were analyzed in the condition in which they were taken, both for IR and XRF analysis. To report the results of the XRF analysis, the calcination residues were also determined.

4.1 The identification of waste samples by FTIR

The waste samples of unknown nature, originating from the railway industry are shown in the figure below (Figure 2). The first sample is presented in the form of a plate fragment made of laminated, resistant, brown-reddish, epoxy composite material. The second sample is a solid waste with lubricating properties, with a dark color. The third sample came in the form of a dark-colored liquid, with no known specifications.



a)

b)

c)

Figure 2. Waste samples analyzed

Sample #1 – solid waste

The sample was prepared by making a filing, which was analyzed at the ATR module of the FTIR Spectrometer equipment. By comparing the spectrum of the sample with the database, a match was obtained for phenolic resin, hence the conclusion that the analyzed sample comes from a textolite-type material.

Figure 3 presents the spectra obtained for the first waste sample.

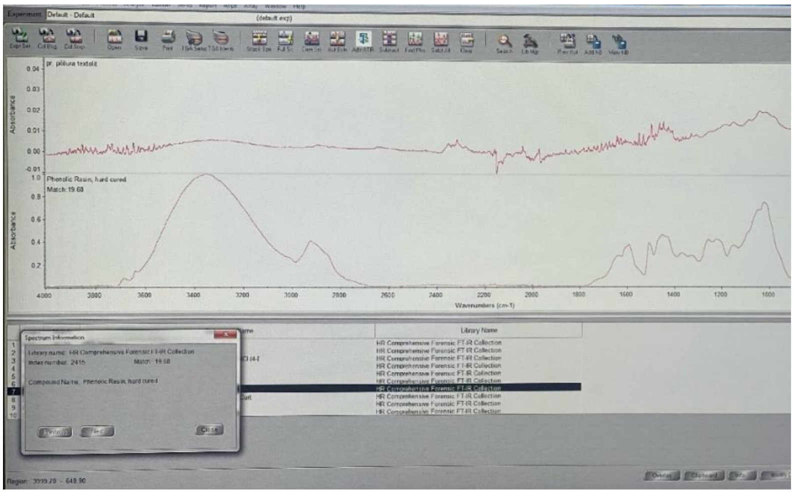


Figure 3. FTIR spectra for waste sample no. 1 (solid sample)

Sample #2 – solid waste

The sample was analyzed in the received state at the ATR module of the FTIR Spectrometer equipment. By comparing the spectrum of the sample with the database, a match was obtained for Vaseline (petroleum jelly) – Figure 4.

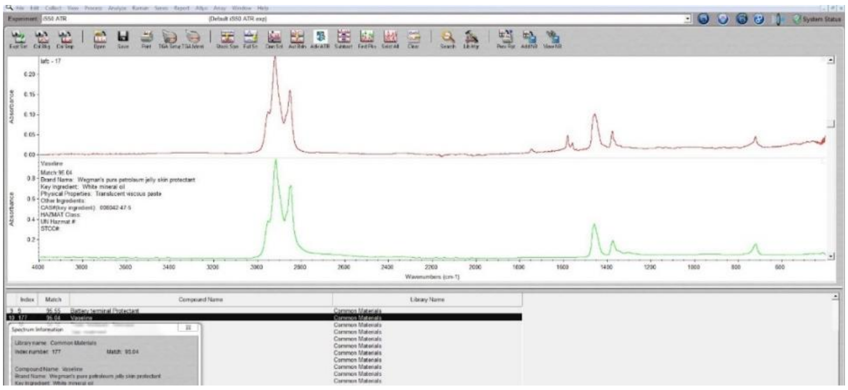


Figure 4. FT-IR spectra for waste sample no. 2 (solid sample)

Sample #3 – liquid waste

The liquid sample was analyzed in the as-received condition at the ATR module of the FTIR spectrometer equipment. By comparing the sample spectrum with the database, a match was obtained for the water-detergent (surfactant) mixture – Figure 5).

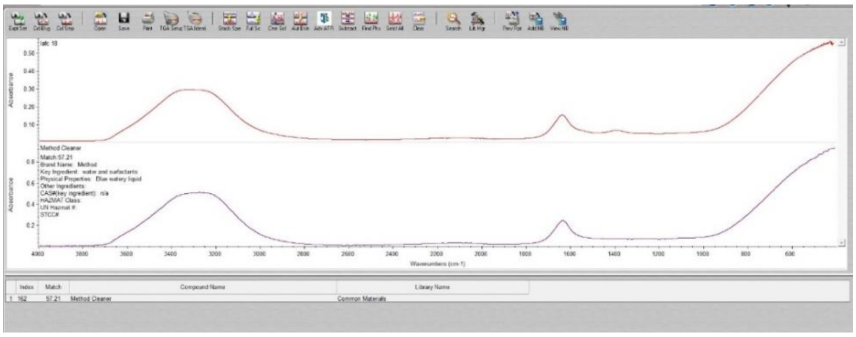


Figure 5. FT-IR spectra for waste sample no. 3 (liquid sample)

4.2 Analysis of metals and oxides by XRF (X-ray Fluorescence) spectrometry

After the XRF analysis, the following components were identified for Sample #1 – see Table 1:

Table 1. XRF analysis results for the first sample (possible Textolite)

Component	**Content (Percentage)**	**Expressed element**	**Content (Percentage)**
Fe_2O_3	0.4980	Fe	0.3486
CuO	0.1994	Cu	0.1593
SiO_2	0.1159		
Al_2O_3	0.0857		
SO_3	0.0200	S	0.0080
CaO	0.0168		
MnO	0.0133		
Cl	0.0106		
MgO	0.0091		
K_2O	0.0090		
P_2O_5	0.0042		

From the calcination residue, there are 2 components identified:

1. Reddish-brown metallic (for this reason Iron Oxide, Copper Oxide, and S Oxide were expressed as elemental Fe, Cu, and S – Table 1, column 3);

2. Fibrous white (Figure 6), most plausible, asbestos or fiberglass.

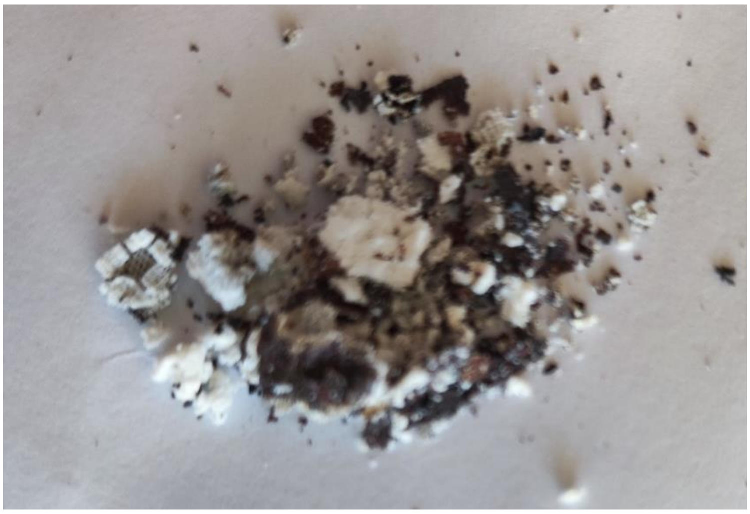


Figure 6. Calcination residue for Sample #1 – solid waste

According to the literature, the asbestos can be one of the following (Table 2):

Table 2. Asbestos types and formula

Name	Chemical formula	Color
Serpentinite	$(Mg,Fe,Ni)_3Si_2O_5(OH)_4$	White - in 95% of cases
Grunerite	$Fe_7Si_8O_{22}(OH)_2$	Brown
Riebeckite	$Na_2Fe^{2+}{}_3Fe^{3+}{}_2Si_8O_{22}(OH)_2$	Blue
Tremolite	$Ca_2Mg_5Si_8O_{22}(OH)_2$	Grey
Actinolite	$Ca_2(Mg, Fe)_5Si_8O_{22}(OH)_2$	White
Anthophyllite	$(Mg, Fe)_7Si_8O_{22}(OH)_2$	Yellow-brown

Since the obtained mineral residue is white, only 2 forms of asbestos can be considered:

a) Serpentinite in the form of $Mg_3Si_2O_5(OH)_4$, in which the elemental Mg/Si ratio is 1.5 and the analysis shows 0.12;
b) Actinolite in the form $Ca_2Mg_5Si_8O_{22}(OH)_2$, in which the elemental Mg/Si ratio is 0.625 compared to 0.12 from the analysis and the Si/Ca ratio is 4 compared to 6.13 from the analysis.

In the case of glass ($6SiO_2 \cdot CaO \cdot Na_2O$ or $6SiO_2 \cdot CaO \cdot K_2O$), the Si/Ca ratio is 6 versus 6.13 resulting from the analysis.

In conclusion, it is estimated that the white material is glass fiber, but it could also be ash resulting from the calcination of some textile fibers.

For Sample #2, identified as Vaseline, the XRF analysis showed the following chemical composition (Table 3):

Table 3. XRF analysis results for the second sample (Vaseline)

Component	**Content (Percentage)**	**Expressed element**	**Content (Percentage)**
SO_3	1.1510	S	0.4604
Fe_2O_3	0.7949	Fe	0.5564
PbO	0.5787	Pb	0.5371
ZnO	0.2025	Zn	0.1625
CuO	0.1529	Cu	0.1222
CaO	0.1094		
K_2O	0.0849		
P_2O_5	0.0331		
SiO_2	0.0316		
Al_2O_3	0.0159		
MnO	0.0125		

Sample #3, the liquid waste, consisted of a liquid and a solid fraction. The liquid fraction is 67.1841%, while the solid (sediment) fraction is 32.8159%.

After the analysis using XRF, the chemical composition of the solid fraction is presented in Table 4, while Table 5 shows the composition of the liquid fraction.

Table 4. Chemical composition of solid fraction, Sample #3

Component	**Unit**	**Value**
Na_2O	%	2.3966
SO_3	%	2.1124
CaO	%	1.7051
Fe_2O_3	%	1.6293
ZnO	%	0.6953
PbO	%	0.2615
SiO_2	%	0.1582
CuO	%	0.1487
K_2O	%	0.1231
Al_2O_3	%	0.0000
P_2O_5	%	0.1156
Cl	%	0.0567
ZrO_2	%	0.0279
MnO	%	0.0209
Cr_2O_3	%	0.0170
SrO	%	0.0111
PC – organic substances	%	90.5272
From which:		
Extractable in petroleum ether	%	15.7705

Table 5. Chemical composition of liquid fraction, Sample #3

Component	**Unit**	**Value**
Na_2O	%	0.0000
SO_3	%	0.8316
CaO	%	0.2401
Fe_2O_3	%	0.9803
ZnO	%	0.7765
PbO	%	0.4037
SiO_2	%	0.9858
CuO	%	0.2208
K_2O	%	0.4004
Al_2O_3	%	0.2858
P_2O_5	%	0.1570
Cl	%	0.0515
ZrO_2	%	0.0986
MnO	%	0.0000
Cr_2O_3	%	0.0721
SrO	%	0.0000
Fixed residues	%	18.4500
From which:		
PC – organic substances	%	12.9426

Taking into account the information from Table 4 and Table 5, we can calculate the chemical composition of Sample #3 – Table 6.

Table 6. Chemical composition of Sample #3

Component	**Unit**	**Value**
Na_2O	%	0.7865
SO_3	%	1.2519
CaO	%	0.7209
Fe_2O_3	%	1.1933
ZnO	%	0.7499
PbO	%	0.3570
SiO_2	%	0.7142
CuO	%	0.1972
K_2O	%	0.3094
Al_2O_3	%	0.1920
P_2O_5	%	0.1434
Cl	%	0.0532

Component	**Unit**	**Value**
ZrO_2	%	0.0754
MnO	%	0.0069
Cr_2O_3	%	0.0540
SrO	%	0.0036
PC – organic substances	%	38.4027
From which:		
Extractable in petroleum ether	%	5.1752

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5 CONCLUSIONS

The use of FTIR (Fourier Transform Infrared) and XRF (X-ray Fluorescence) analytical methods in the identification and characterization of industrial waste offers a comprehensive approach to managing and mitigating environmental impact. FTIR's ability to provide detailed molecular information through infrared absorption spectra makes it an invaluable tool for identifying organic compounds and complex chemical mixtures, while XRF's capability to detect and quantify elemental composition complements this by offering precise information on inorganic constituents and heavy metals. Together, these techniques enable a thorough analysis of industrial waste, facilitating accurate identification of hazardous substances and enhancing the formulation of effective treatment and disposal strategies. Their combined application represents a significant advancement in industrial waste management, underscoring the critical role of advanced analytical methods in safeguarding public health and preserving ecological integrity.

For this work a series of analyses were performed over three waste samples, one liquid and two solids, originating from the railway industry. All samples were analyzed in the condition in which they were taken, both for IR and XRF analysis. The analyses were needed for the beneficiary to elaborate the waste documentation both for deposit or for the waste reutilization. The main conclusions were that the analyzed wastes were a textolite material, a vaseline waste, and a surfactant mixture with specific metal oxide concentrations, that will be used for the correct waste management imposed by the current regulations.

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DETERMINING THE AUTO-IGNITION TEMPERATURE OF PROCESS PETROLEUM PRODUCTS

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Abstract: *The process underlying petroleum refining is distillation, which is a physical process of separating the components of a mixture based on their boiling point. Petroleum is a mixture of solid and gaseous hydrocarbons dissolved in a mixture of liquid hydrocarbons. Crude oil contains a series of organic substances (alkanes, cycloalkanes, aromatic hydrocarbons) organic compounds with nitrogen, oxygen, sulfur, etc. Self-ignition is caused by exothermic (heat-generating) oxidation reactions. The temperature at which auto-ignition occurs is a measure of the sensitivity of the substance to oxidation (the oxidability of the substance.) The auto-ignition temperature is the lowest temperature at which a substance will ignite spontaneously in a normal atmosphere without an external source, such as sparks or flames. The purpose of this paper is the determination, according to SR EN 14522:2006 - Determination of the auto-ignition temperature for gases and vapors. The results obtained after the determinations are used for the increasing safety of the personnel and process, for the optimization of the process parameters (temperatures, pressures, etc.) and to avoid unwanted events such as fire or explosion.*

Key words: *auto-ignition temperature, petroleum products*

1 INTRODUCTION

Petroleum products are flammable substances. They are used as household and industrial fuels, solvents for oils or in various chemical syntheses.

Pipelines and tanks with petroleum products, especially volatile ones, the risk of fire and explosion, in case of accidental leaks, flammable vapors spread very quickly % of elementary composition.[5]

Apart from these elements, crude oil also contains sulphur, oxygen, nitrogen. In the ash of crude oil, we find SiO_2, Fe_2O_3, Al_2O_3, CaO, MgO, V_2O_3, NiO, Na_2O. The oil of the bank in a complex mixture of hydrocarbons of molecules of different sizes, open with the smallest with this methane up to large molecules that have a very high molecular mass.[3]

Crude oil is a complex mixture of hydrocarbons, the hydrocarbons in petroleum have all the possible molecular weights from 16 in the case of methane to 1800. From the class of alkanes, most of the normal alkanes up to C50 have been identified. The isomers of butane, hexane, a large part of the isomers of heptane, octane

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was identified. From the class of cycloalkanes, the following were isolated: cyclopentane, cyclohexane, mono, di, tri-halogenated derivatives.[1]

Among the aromatic hydrocarbons, benzene, toluene, xylenes were identified.

All crude oils are a mixture of three classes of hydrocarbons namely: saturated acyclic hydrocarbons (alkanes) saturated hydrocarbons. The class of alkanes is represented by cyclopentane and cyclohexane as well as derivatives substituted at the groups. Crude oil may also contain organic acids and sulfur removed during processing.[8]

Crude oil is a homogeneous mixture of complex hydrocarbons that at the temperature and pressure of the ambient environment is found in a liquid state. In addition to hydrocarbons, crude oil also contains other elements of an organic nature, oxygen, sulfur, nitrogen or phosphorus. [2] Analyzing the ash results (by burning crude oil) small amounts of calcium, magnesium, iron, aluminum, manganese, nickel was found.[7] The heated crude oil is pumped to the middle of the distillation column. The temperature varies along the column being the lowest at the top and the highest at the bottom.

Petroleum is a viscous liquid that varies in color from yellow-green to black. It is not soluble in pressure. It is easier than this. Because it is a mixture of different organic compounds, oil does not have a well-established boiling point. It is continuously distilled in the range of 30-360°C. Distillation is the separation field that is the basis of oil refining. being a physical vapor separation, the results are then condensed by cooling.[6] The operation is called fractional distillation to obtain mixtures of saturated hydrocarbons with close boiling points which are called fractions. [10]

Liquid fuels are made up of hydrocarbon mixtures

Synthetic fuels result from the catalytic cracking of petroleum or the thermal hydrogenation of coal.

-gasolines with a boiling temperature (30÷205°C) are used in internal combustion engines with spark ignition

- lamp oil (kerosene) boiling temperature (150÷205°C) use the turbo engines of airplanes

-diesel with boiling temperature in the range (200÷380°C) used for diesel engines

- fuel oil with a boiling temperature (300÷550°C) used in the energy field when burning in the hearths of steam generators

Commercial gasolines for cars are mixtures of C_5-C_{10} hydrocarbons (alkanes, cycloalkanes):

-The C_1-C_4 fraction called light gases are used as raw materials and as fuel

- The C_5-C_6 fraction called light gasoline - is the main constituent of gasoline

- Fraction C_6-C_{10} heavy gasoline naphtha (raw material for gasoline)

-C_{11}-C_{15} fraction called kerosene -used in jet engines and lamp oil

- The C_{12}-C_{20} fraction is called diesel - fuel in diesel engines

-The fraction C_{20} is called atmospheric residue -it is a solid residue used for lubricants, fuel oil and asphalt

Before processing, oil contains solid contaminants (up to 1.5%) and water (up to 0.3%). Some of the insoluble contaminants and water are removed from the oil by sedimentation.[9] The process involved simply storing oil in storage tanks for a period of time, during which the solids and some of its water content migrate to the bottom, while the other solids dissolve in the water, forming a brine, which. it's pretty hard to do remove. In that emulsion, oil is the dispersion medium, while salt water is the dispersion phase.[4]

The purified and degassed oil is made to flow into a tube furnace to be heated to a temperature not exceeding 370°C and then to the base of a first distillation tower (atmospheric column). The distillation tower is approximately 40 m high and comprises a number of so-called trays.

Some examples of auto-ignition temperatures for flammable liquids are in table no1.

Table 1 Auto-ignition temperatures for flammable liquids

Name of substance	Autoignition temperature
Petroleum	400°C
Benzen	560°C
Butane	420°C
Etane	515°C
Fuel oil 1	210°C
Fuel oil 2	256°C
Heavy hydrocarbons	750°C
Isobutane	462°C
N heptane	215°C
N octan	220°C

While these temperatures are well outside the normal working temperature range of workplaces, self-ignition can occur at workplaces when there is a very high ambient temperature. This could include spontaneous combustion during a workplace fire, chemical transport, manufacturing processes or other circumstances that can trigger a thermal reaction.[4]

Self-ignition, by its very nature, is dependent on the chemical and physical properties of the material and the method and apparatus used for its determination.[10]

The autoignition temperature by a particular method does not necessarily represent the minimum temperature at which the material will auto-ignition in air. [6] The volume of the vessel used is particularly important because lower auto-ignition temperatures will be achieved with larger vessels. The temperatures determined by this test method are those at which air oxidation leads to ignition. These temperatures are expected to vary with test pressure and oxygen concentration.

The test method is not designed to evaluate materials that are capable of exothermic decomposition. For such materials, ignition is dependent on the thermal and kinetic decomposition properties, the mass of the sample, and the heat transfer characteristics of the system. This test method can be used for solid chemicals that melt and vaporize or sublimate easily

The self-ignition range of a chemical is tested by placing it in a small vessel - which is then transferred to a temperature-controlled oven. By controlling the oven temperature, you can determine the heat at which the chemical spontaneously ignites. This ensures the auto-ignition temperature of the substance.

This standard test method is designed to determine the auto-ignition temperatures of flammable vapors in air-air mixture at ambient pressure and temperature up to 650°C.

After the internal temperature of the flask reached the desired temperature, I adjusted the temperature controller to keep this temperature within the set limits and let the system equilibrate.

The sample of approximately 50÷300 µL is introduced into a uniformly heated flask containing air at a predetermined temperature. After introducing the sample, self-ignition will be observed in a dark room.

The occurrence of self-ignition by the sudden appearance of the flame outside the flask, sour is found inside the furnace, followed by a sudden increase in the temperature of the gas mixtures.

The general combustion reaction of alkanes:

$$CnH_{2n+2} + 3n+1/2\ O_2 \Rightarrow (n+1)\ H_2O+CO_2+Q \qquad (1)$$

The complete combustion reaction of octane, a representative alkane in the case of gasoline

$$C_8H_{18} + 25O_2 = 16\ CO_2 + 18\ H_2O \qquad (2)$$

2 TEST METHOD

The sample, approximately (50 to 300) µl, was introduced into a uniformly heated 200 ml glass flask containing air at a predetermined temperature. Autoignition behavior of the substance in the flask was observed in a dark room for 10 minutes after introduction of the sample or until autoignition occurred. Self-ignition is evidenced by the sudden appearance of a flame inside the flask and by a sudden increase in the temperature of the gas mixture.

When the mixture ignited at the predetermined temperature, the next sample was tested at a lower temperature. These procedures were repeated until the lowest temperature at which an ignition of the mixture was obtained. The amount of sample added was then systematically varied.

Determination of the lowest temperature at which hot flame ignition occurs and was considered to be the AIT (autoignition temperature) of the substance or mixture of chemicals in air at atmospheric temperature. pressure. Bleeding was performed between two consecutive samples

To avoid interferences caused by ambient temperature, a 10-minute thermal equilibration time is considered between tests. During the determinations, the ambient temperature is controlled at approximately 20°C. The lowest internal flask temperature (T) at which hot flame ignition occurs for the series of prescribed sample volumes is taken as the hot flame autoignition temperature (AIT) of the chemical at atmospheric pressure.

As determined by this method, it is the lowest temperature at which the substance will produce hot flame ignition in air at atmospheric pressure without the aid of external sources such as spark or flame. [7]

The auto-ignition temperature is the lowest temperature to which the temperature of a combustible mixture must be raised so that the rate of heat released by the exothermic oxidation reaction will overbalance the rate at which heat is lost to the surroundings and cause ignition. Self-ignition is evidenced by the sudden appearance of a flame inside the balloon and by a sudden increase in the temperature of the gas mixture.

The apparatus consists of an electric oven, provided in the upper part with a hole, inside which there is a flask made of heat-resistant glass, the temperature being measured with two thermocouples, placed at the bottom and side of the flask. The furnace is capable of maintaining auto-ignition temperature of 650°C or above.[11]

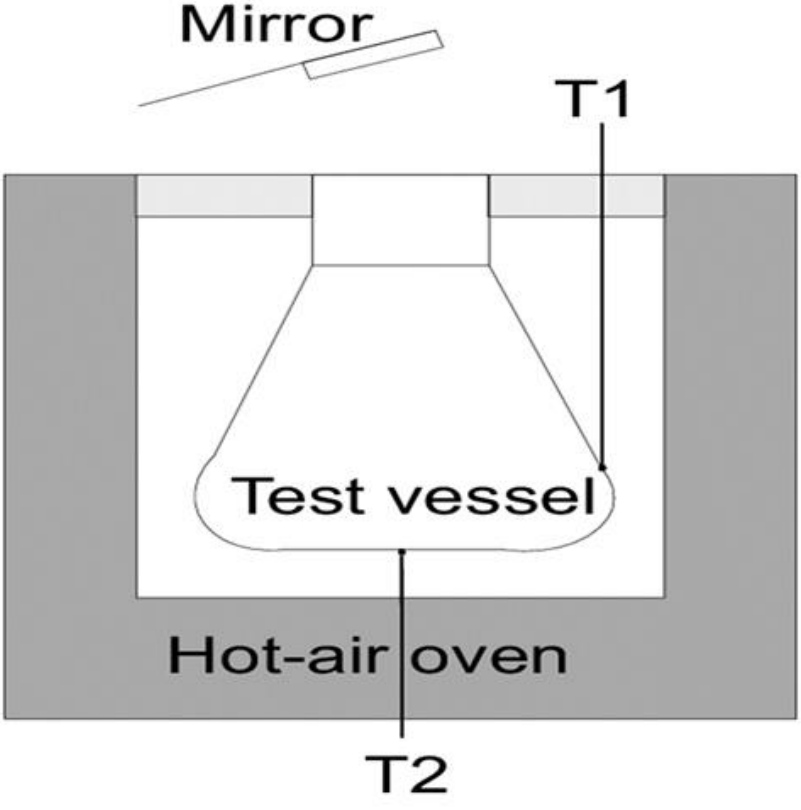

Figure 1 Schematic view experimental setup

Experimental setup include: Erlenmayer flask 200ml, oven with heat isolation, temperature control system
T_1-thermocuple ignition temperature
T_2-Thermocuple oven temperature

Foto no 1: The sample introduction in test vessel

Foto no.2: Moments of ignition

The risk of autoignition of a substance depends on the difference between the rate of heat generation in a mixture and the rate of heat loss to the walls of the flask. The characteristics of the thermal effects when a combustible liquid is introduced into the test flask at different initial temperatures can be illustrated by temperature curves over time. Ignition is defined as the appearance of a flame accompanied by an increase in the temperature of the gas-air mixture.

3 RESULTS AND DISCUSSION

Minimum ignition temperature determined in experiments is in table no2.

Table 2. Minimum ignition temperature determined in experiments

Type of petroleum products	Determined autoignition temperature
Hydro fined diesel	220°C
Naphtha	230°C
Tar	350°C
Oil	330°C
Heavy diesel	360°C
Light diesel	240°C
Gasoline BU	350°C

In the case of the auto-ignition temperatures determined, it can be observed that the values of the auto-ignition temperatures in the case of heavier products that have in their composition products with a higher molecular mass are higher than for petroleum derivatives that have in their composition components with a lower molecular mass.

4 CONCLUSIONS

In this work, the auto-ignition temperatures of various petroleum products were determined in accordance with SR EN 14522:2005. Autoignition temperatures have been determined for a variety of compounds that are obtained from the processing of crude oil. Petroleum products are obtained and circulated within the process oil industry.

In this way, auto-ignition temperatures were determined in the case of different types of diesels with values between 220÷360°C, and 230÷350°C for the different types of gasoline.

Petroleum products being a mixture of different hydrocarbons (aliphatic, linear, cyclic, aromatic) have different auto-ignition temperatures, their determination and knowledge is particularly important in preventing fires and explosions, which can have disastrous effects in the process oil industry.

Acknowledgment

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EVALUATION OF THE SELF-IGNITION TEMPERATURE OF DUST ACCUMULATIONS - CASE STUDY DRY VEGETABLE MATTER

Andrei SZOLLOSI-MOȚA[1], Vasilica Irina NĂLBOC[2], Asimina TOPLICIAN[3]

Abstract: *Ignition and spontaneous combustion (self-ignition) can occur when a combustible substance with a relatively low ignition temperature (hay leaves, cereal straw, vegetable waste, peat) releases heat. The release of heat can occur in different ways either by oxidation in the presence of moisture content and oxygen in the air or through bacterial fermentation which will generate heat. Heat dissipation is blocked because plant materials such as (leaves, straws, hays) are good thermal insulators, thus producing an increase in the temperature of the material to a temperature equal to or higher than its auto-ignition point. Even at normal temperatures, molecules on the surface of combustible dust particles undergo exothermic interactions with oxygen from the air carried in the free volume between the particles, which is the fundamental cause of self-heating (or perhaps self-ignition). The temperature in the reactive dust and air system will then rise as a result of any heat given off, hastening the reactivity of subsequent dust molecules with oxygen. Combustible powders can self-ignite depending on a variety of variables, including their chemical composition, the characteristics of the constituent parts, the particle size and geometry of the material mass, and not least the surrounding temperature. Spontaneous combustion is a phenomenon resulting from the heating of powders of an organic nature (vegetable residues) by slow oxidation and takes place with the passage of air through the mass of fine vegetable matter. The purpose of this paper is to study the self-ignition behaviour of combustible vegetable matter originating from the shredding of organic vegetable matter.*

Keywords: *autoignition temperature, vegetable*

1 INTRODUCTION

"Dust" is the well-known notion for materials obtained by crushing solids beyond a certain degree of fineness. This notion therefore also includes materials commonly known as powder, flour, powder, etc. Dust consists of a lot of solid particles, whose main property, which distinguishes them from other fragmented solids, is their very low rate of fall ignition in general and in air in particular. Dust particles in a volume of air, without touching each other, form a mixture of powder -

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air. In this case the air is the dispersing agent, and the powder particles are called the dispersed phase. Such mixtures have in some respects similarities to gaseous mixtures. When powder particles are at rest on a substrate and touch each other, they are referred to as "powder layers" or "powder deposits".

Ignition and spontaneous combustion can occur when a substance with a relatively low ignition temperature (leaves, peat, hay, straw, fir needles) will release heat. The release of heat can occur in different ways either by oxidation in the presence of the content of moisture and oxygen from the air or through bacterial fermentation which will generate heat. Heat dissipation is blocked because plant matter such as (leaves, straw, hay). These materials are good thermal insulators, thus an increase in the temperature of the material occurs at a temperature equal to or higher than its auto-ignition point. Spontaneous combustion is a phenomenon resulting from the heating of organic powders (vegetable residues) through slow oxidation and has place by the passage of air through the mass of fine vegetable matter.[7]

The phenomenon of oxidation of combustible powders, their reaction with oxygen in the atmospheric air, resulting in gaseous reaction products: carbon dioxide, carbon monoxide, water and other gaseous substances.[5]

The purpose of these works is to study the self-ignition behaviour of the combustible dust originating from the shredding of plant materials.

OSHA defines combustible dust as “a solid combustible material, composed of distinct pieces or particulates that presents a fire or deflagration hazard when suspended in air or some other oxidizing medium over a range of concentrations, regardless of particle size or shape.” When suspended in the right concentration and exposed to an ignition source, these dust particles can lead to fires, deflagrations or explosions that can cause chain reactions throughout a facility—and with potentially deadly results.

In the case of the burning of solid substances such as vegetable matter, in order for combustion to take place, volatile substances are emitted from the solid surface, mix with the surrounding air and produce a flammable mixture that ignites either as spontaneously with a sufficiently high temperature.[2].The high exothermicity of flaming combustion results in a pronounced increase in temperature causing rapid pyrolysis and the production of volatiles that will ignite and sustain combustion. When volatile substances are depleted by combustion and the rate of production of these substances decreases, the combustion will become a smouldering combustion. The intrinsic properties of plant matter are moisture content, lignin and cellulose [3,4]

The presence of water, usually expressed as moisture content, is often considered to be the most important parameter governing the initiation, propagation and course of combustion. Chemical composition containing a broad group of chemical compounds (e.g. aliphatic and aromatic hydrocarbons, aldehydes, alcohols, sugars, terpenes, fats, waxes and oils) which, compared to other organic components of vegetable fuels, will release more heat following combustion processes.[6]

The ash content slows down the burning of the flame, among the ash components silicon is considered inert and does not affect combustion. The ash content reduces the heat content of the fuel.[1]

Cellulose and lignin behave differently when exposed to heat. Cellulose tends to undergo rapid pyrolysis, producing mostly volatile substances, while lignin exhibits higher temperature resistance.

Individual fuel particles are constituents of fuel layers and of the fuel complex as a whole, and thus their size and shape inevitably influence combustion. Fuel particle size has been shown to be an important factor in governing the moisture uptake and desorption of vegetable fuel.

Combustion behaviour of leaves and leaf litter, promoting longer and larger leaves lead to faster ignition and fire spread and more intense flames Combustion and spontaneous ignition of vegetation material has been well investigated due to the ignition risks of the materials with cellulose and lignin content. [7,9]

Fuels drier than air will absorb moisture, and fuels wetter than air will desorb it. Under conditions of constant air temperature and humidity, the process of adsorption or desorption will continue until equilibrium is reached between air and fuel. [8]

As a few days of hot and dry weather can be enough to dry the plant matter to the point where it is easily ignited. Self-ignition of materials through pyrophoric sulphide materials

$FeS_2+O_2 = FeS + SO_2 +$ heat

Moisture accentuates the self-ignition of processes in the case of reactions of some reactions

$Na+H_2O = 2NaOH+H_2+$heat

Among the oxidants with the greatest oxidizing power are nitric acid (it can ignite organic materials such as straw, mulch, etc.), sodium peroxide, chlorates and perchlorates. Self-ignition of a physical-chemical nature is specific to combustible substances, which, apart from the chemical process, are also subject to the influence of some factors, such as a large contact surface with atmospheric oxygen, insufficient evacuation of the heat produced and the existence of some impurities. Examples of physical-chemical self-ignition can be yes: self-ignition of coal, coal dust, ammonium nitrate, cotton, oil varnishes, seeds and sunflower cakes.

Powders are solid substances dispersed in uniform particles with a determined degree of division, they are obtained from dry and shredded solid organic substances. Cutting the vegetation does not result in the immediate death of the plant cells that make up the vegetation. Cells continue to breathe until food and moisture are sufficient. The respiration process of plant cells provides heat until temperatures rise to lethal levels between 25-50°C. When plant cells die, various water-soluble cellular metabolites are released, such as sugars, amino acids, organic acids.

These substances provide food for the bacteria, and the microflora vegetation breathes and transforms glucose and oxygen into carbon dioxide and heat.

$$C_6 H_{12} O_6 + 6 O_2 = 6 CO_2 + 6 H_2O + \text{energy} \quad (1)$$

Carbon dioxide, being an inert gas, prevents the access of air from the atmosphere, thus interrupting the normal aeration of the vegetable matter.

Feedback

The experimental determination of self-ignition temperatures as a function of volume is necessary for the evaluation of the self-ignition hazard of bulk materials. Two standardized techniques are available for this purpose: measuring the self-ignition temperature of a layer of dust put on a heated surface and determining the self-ignition temperature of dust samples in an oven. Sometimes, depending on how the sample behaves during these tests, the second method is difficult to use.[15]

Combustible dusts can self-ignite depending on a variety of variables, including their chemical composition, the characteristics of the constituent parts, the particle size and geometry of the mass of the material, and last but not least, the surrounding temperature.[10]

Even at normal temperatures, molecules on the surface of combustible dust particles undergo exothermic interactions with oxygen in the air carried in the free volume between particles, which is the fundamental cause of self-heating (or maybe self-ignition). The temperature in the system of reactive dust and air will then increase as a result of any heat emitted, hastening the reactivity of further dust molecules with oxygen. The system's evolution will depend on the thermal balance between the heat produced inside the dust mass (quantity and surface area of surface reactive molecules, calorific value) and the heat lost to the environment [12,13]

Self-ignition is a common source of ignition of porous storage of bulk materials such as powders and dusts. Evaluation of this ignition hazard, taking into account manufacturing or storage conditions, requires experimental determination of critical self-ignition temperatures as a function of volume [8].

The specified test is applicable to any dust or granular material that reacts primarily with oxygen from the air. For safety reasons, this test is not used with materials mixed with solid/liquid oxidant (e.g. gunpowder, thermites, wood impregnated with liquid oxygen) or materials that could undergo violent non-oxidative reactions (e.g. peroxides, explosives).

On a case-by-case basis, some types of materials undergoing non-oxidative reactions (e.g. non-violent exothermic decomposition reactions) may be however tested provided that additional safety precautions are taken. Where any doubt exists about the existence of hazard due to the properties of the test material (e.g. toxic or explosive), expert advice is sought.[11]

2 WORKING METHOD

Combustible dust and topsoil can self-ignite depending on a variety of variables, including their chemical composition, the characteristics of the constituent parts, the particle size and geometry of the material mass, and last but not least, the surrounding temperature.

The oven used is of the POL EKO type. The forest soil sample is taken from the spreading area of deciduous forests (mostly beech Fagus Sylvatica). The forest soil sample was heated from the initial temperature of 30°C.

It has been demonstrated that self-ignition is possible, if the soil temperature is below a certain calculated value the risk of vegetation re-ignition is low. Temperature plays an important role in these processes as the rate of reaction increases with increasing temperatures. In addition to the chemical oxidation reactions that contribute the most important exothermic component to the overall process.

Physical and microbiological processes play a role in the thermal regulation of bulk materials in forest soil biomass. For example, water adsorption on relatively dry solid surfaces can lead to an increase in temperature as heat of adsorption is released.

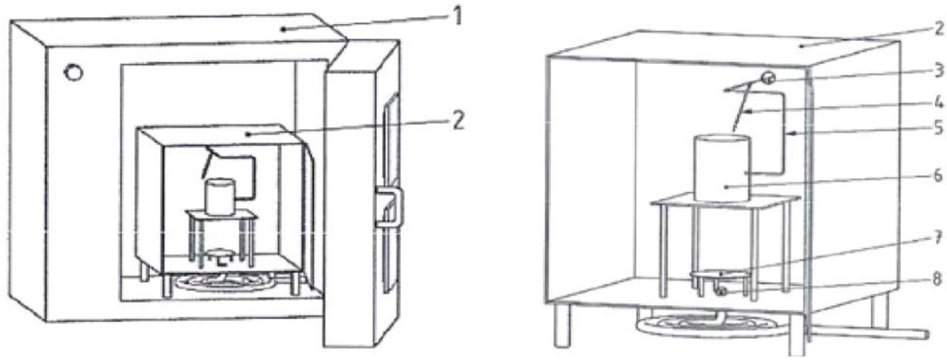

Figure. 1. Experimental assembly for hot steaming tests
1 - heating oven; 2 - inner enclosure; 3 - air outlet, diameter = 10 mm air inlet (preheated air, flow); 4- thermocouple for temperature measurement; 5 - thermocouple for measuring the sample temperature; 6 - wire mesh cylinder, with dust sample; 7 - deflector

Figure 2: Stand for determining the self-heating temperature

In order to investigate the self-ignition behaviour, a programmable oven is used. Two K-type thermocouples are used to measure the temperature. The method is used to determine the auto-ignition temperature of dust samples, but other types of samples such as bulk samples can also be investigated.

To investigate the self-ignition behaviour, the SR EN 15188:2021 standard is used - Determination of the self-ignition behaviour of dust accumulations. The samples are placed in cylindrical wire baskets with different volumes: 180 cm3, 380 cm3 and 995 cm3.

To determine whether or not self-ignition occurs, there are two methods:

A. When the temperature in the centre of the sample rises at least 60 K above the oven temperature

B. When the temperature at the centre of the sample exhibits an inflection point, relative to time, if it appears above the oven temperature. -figure 2.

Figure 3. Autoignition of samples of vegetable soil samples

Figure 4. Autoignition of samples of vegetable soil samples

Figure 5. Autoignition of samples of vegetable soil samples

Autoignition of samples of vegetable soil samples (Figure 2,3,4)

As a result of the self-ignition process, white smoke was released.

Smoke comprises several types of components: solid particles including soot, semi-volatile organic compounds, solid organic compounds and highly volatile compounds.

During the burning of vegetable matter and wood, the most significant gases that are released through smoke are: carbon dioxide, acetone, acetaldehyde, hydrocyanic acid, benzene, formaldehyde, ethanol, sulphur dioxide, ethanol, carbon monoxide.

3 RESULTS AND DISCUSSION

Table 1. Dependence of autoignition temperature from volume

Characterization of the sample	Vegetal soil volume (cm^3)	Autoignition temperature °C	Induction time (h)
	180	250	0,3
	380	220	0,6
	995	200	1

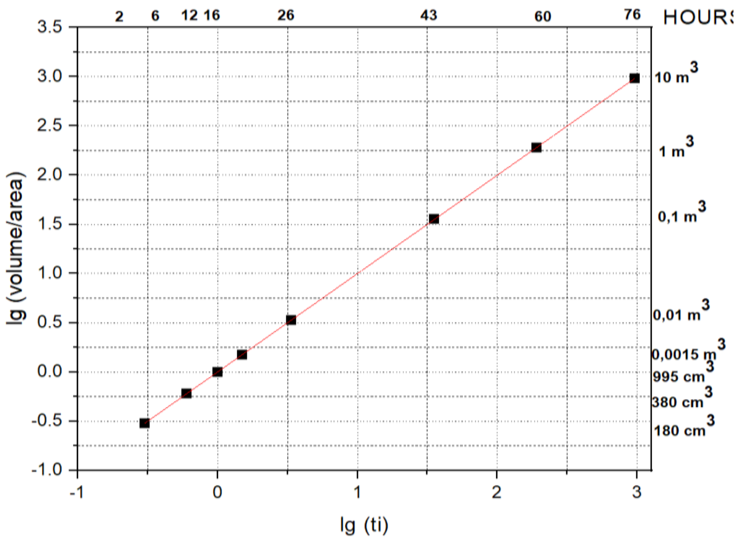

Figure 6. Dependence of combustion induction time (ti) on the volume/surface ratio

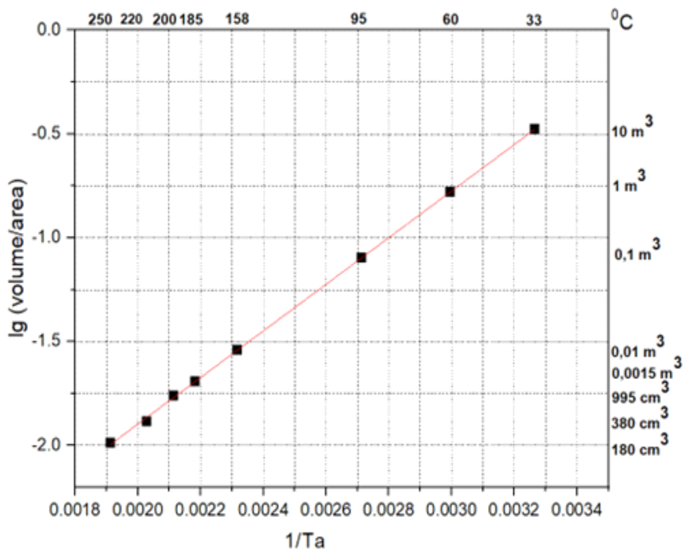

Figure 7. Graphic representation of ignition temperatures according to Arrhenius for vegetable soil

The smouldering combustion of vegetable matter following self-ignition in an oven-smoke release. The composition in metal oxides of the vegetable soil was determined by means of the XRF analysis method with the help of the XRF Supermini 200 spectrometer. Within the self-ignition processes, the contents of metal oxides of the vegetable soil are particularly important. As a result of the analysis, different oxides characteristic of plant matter was obtained, such as iron oxides, sulphur oxides.

Table 2. composition in metal oxides of the vegetable soil

Substance	Composition
SiO_2	24,5%
MnO	4,59%
K_2O	4,40%
P_2O_5	3,68%
SO_3	3,61%
MgO	3,04%
Fe_2O_3	2,46%
Al_2O_3	1,65%
Cl	0,929%
Cr_2O_3	0,612%
NiO	0,378%

Figure 8. XRF apparatus image

Self-ignition processes of iron sulphides.

$4FeS + 3O_2 = 2Fe_2O_3 + 4S + Q$

The reaction between iron sulphide and oxygen is accompanied by the generation of a considerable amount of heat.

4 CONCLUSIONS

In this study, experiments were carried out regarding the auto-ignition temperatures of the plant materials studied. The experiments were carried out from an initial temperature of 30°C.

The auto-ignition temperature for the plant materials studied was determined to be higher than 200°C. The experimental results showed that the plant material tested is combustible and has a tendency to self-ignite at temperatures above 200°C and based on the graphs obtained, as a result of the experiments carried out, safety measures can be taken to avoid fires.

Vegetable materials in certain specific conditions can self-ignite, this fact being demonstrated through the tests carried out, by subjecting it to heating in an oven and from the data obtained from the specialized literature.

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DEVELOPMENT OF EXPERIMENTAL MODELS BASED ON APRIORI STUDIES OF HYDROGEN EXPLOSIONS EFFECTS

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Abstract: *Taking into account previous research conducted by INSEMEX Petrosani in the field of gas mixture explosions, particularly methane explosions, the transition to investigating hydrogen explosions required studying the explosive characteristics of this gas and adopting experimental models that meet safety requirements in use, due to the much more aggressive behavior of hydrogen compared to methane in the explosive process. Aspects covered within this article highlight the research performed by INSEMEX with regard to virtual tests of hydrogen explosions conducted prior to the design and development of the experimental models. The results of these tests subsequently served for selecting the materials, configuring the experimental models, and for sizing them. Considering that the future physical experiments are aimed at obtaining data from hydrogen explosions in interconnected spaces, the arrangement and division of the experimental models into combustion chambers were also analyzed on the basis of virtual tests. Thus, two experimental models have been developed. The first model is intended for analyzing the linear propagation of hydrogen explosions through interconnected chambers. For the second model, a rectangular spiral path was adopted, with interconnected chambers arranged along it and explosions initiated in the central chamber, while maintaining the cross-section and propagation length corresponding to the linear stand. This dimensional consistency will be useful in comparative studies regarding the hydrogen explosion process on linear and non-linear trajectories.*

Key words: *hydrogen, explosion, experimental, ignition, test*

1 INTRODUCTION

The main objective of creating enclosed space models is to obtain suitable input data sets for precise computer simulations regarding chemical explosions of air-hydrogen mixtures in interconnected enclosed spaces and open spaces. This objective consists of two sub-objectives:

- Obtaining an adequate data set for simulating hydrogen explosions in interconnected enclosed spaces, a sub-objective achievable by validating simulation results through comparative analysis with data recorded during physical experiments;
- Obtaining a suitable data set for conducting and validating simulations of hydrogen explosions in open spaces, a sub-objective achievable through a comparative

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study of simulation results obtained using the ANSYS FLUENT application with those obtained using software dedicated to this type of explosion (PHAST).

Achieving the first sub-objective involves creating experimental models adapted to hydrogen explosions (much more aggressive than methane, butane, or propane explosions), while also meeting the transparency requirements necessary for Schlieren recording techniques.

The second sub-objective aims to obtain approximately identical maps of overpressure values generated by hydrogen explosions in open spaces by running two different applications (PHAST and FLUENT). [1]Considering that the PHAST application performs 2D simulations of this type of event, the justification for the sub-objective is given by the virtual 3D representation of the phenomenon, with the FLUENT application highlighting both direct, reflected, and combined shock waves, and the results being comparable to reality.

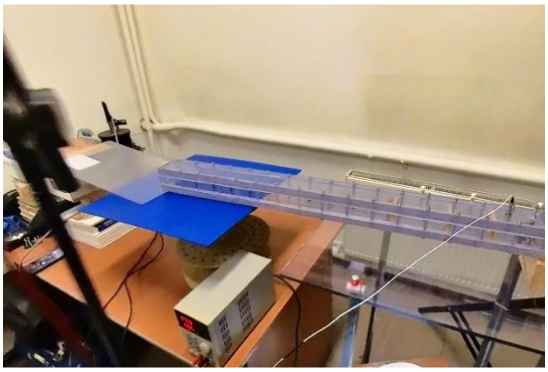
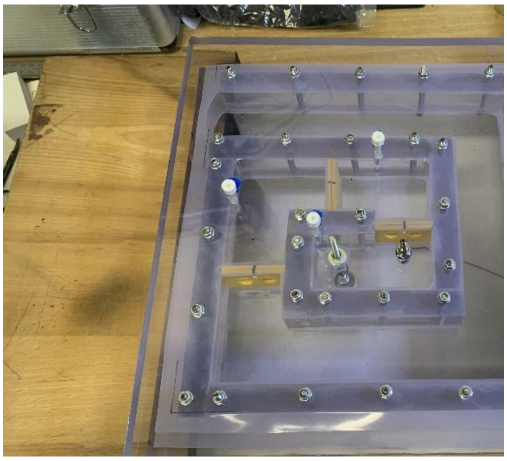



Figure 1. Images of the linear stand and the spiral stand

The achievement of the overall objective of creating models is conditioned by the fulfillment of the following specific research and administrative objectives:

- Designing experimental models used for analyzing explosions of air-hydrogen mixtures in enclosed spaces;
- Developing and instrumenting the experimental models;
- Testing the functionality of the experimental models used for analyzing explosions caused by air-hydrogen mixtures in enclosed spaces;
- Conducting physical experiments on the initiation of explosive air-hydrogen mixtures in enclosed spaces;
- Performing an experimental study on the linear propagation of explosions caused by air-hydrogen mixtures in enclosed spaces;
- Conducting experiments on the behavior of explosions caused by air-hydrogen mixtures in enclosed spaces due to changes in the direction of propagation;
- Translating the experimental models into the virtual environment;

- Conducting CFD simulations and calibrating them to obtain specific parameter sets suitable for use in CFD simulations of air-hydrogen explosions in enclosed spaces;
- Comparing the results obtained from physical experiments with those obtained using CFD simulations;
- Using specialized software for the numerical modeling of discharge, atmospheric dispersion, and hydrogen explosions in open spaces;
- Incorporating the results obtained through specialized software into the CFD model to obtain specific parameter sets suitable for use in CFD simulations of air-hydrogen explosions in open spaces;
- Conducting a case study on the applicability of the CFD model for analyzing hydrogen explosions in open spaces;
- Carrying out coordination, reporting, result dissemination, and intellectual property protection activities.

The project uses both various scientific research methods aimed at developing ways of acquiring knowledge in the studied field and a series of principles/rules for conducting investigations and using working tools to collect and interpret recorded theoretical and experimental data.

2 EXPERIMENTAL SETUP AND METHODOLOGY

2.1 The development of safety criteria and the use of experimental models

In the first phase of the project, the focus was on creating experimental models for analyzing the linear propagation and the propagation direction change of explosions caused by air-hydrogen mixtures, as well as conducting tests for initiating air-hydrogen atmospheres, recording pressures, and applying Schlieren video recording techniques.

For conducting physical experiments (explosions of air-hydrogen mixtures) under safe conditions, while considering the requirements for the accuracy of recording explosion process parameters and those imposed by recording techniques, as well as the use of experimental models in complex scenarios, the following design criteria were developed:

- Allow the use of Schlieren techniques for continuous monitoring and recording of the rapid combustion process. For this, the experimental model must have transparency along the vertical recording axis and fit within the circumference of the parabolic mirrors (with a diameter of 412.8 mm) required by these techniques;
- Allow the configuration of the model in interconnected spaces by placing obstacles with membrane-covered orifices;
- Allow the use of membrane obstacles with orifices of different shapes (circular, square, rectangular, elliptical, etc.) and membranes of different thicknesses;
- Ensure a high degree of precision in measuring local/global velocities and accelerations;
- Ensure the possibility of recording pressure values in each interconnected space;

- Allow the analysis of pressure variations when changing the propagation direction of gas explosions and when penetrating obstacles of different resistances;
- Allow the analysis of chain gas explosions;
- Allow the testing of explosion suppression curtains (using nitrogen, water, etc.);
- Allow the modification of the ignition source location;
- Be resistant to the overpressure values generated by the explosion.

Considering that a more complex experimental model is used for explosions with changing pressure wave propagation direction, it is considered that the experimental model used for analyzing linear propagation explosions can be constructed under the same conditions (in terms of materials used). This is motivated by the fact that the overpressures generated by air-hydrogen mixture explosions, in the case of changing propagation direction, are higher than those generated by linear propagation explosions.

2.2 The design of the experimental prototype and its testing in the virtual space

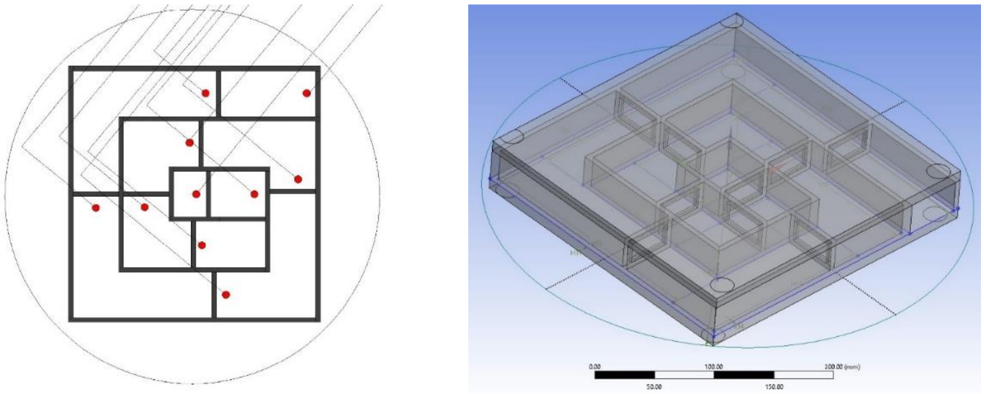
Considering the criteria listed above, the experimental prototype was designed in the form of a rectangular spiral with metallic walls to ensure the material's resistance to overpressures acting horizontally. The spiral shape allows for analyzing the explosion process with changes in propagation direction; along this path, membrane obstacles are placed to divide the interior volume of the spiral into separate chambers.[2]

To meet the transparency criterion along the vertical axis (required by Schlieren recording techniques), the metallic spiral is closed at the bottom and top with two polycarbonate plates, a material that provides both transparency and resistance to overpressures.

Thus, high-speed video recordings will benefit from the experimental model's vertical transparency, ensuring the capture of data regarding fluid velocities in the explosion process and the observation of flame front behavior, as well as marking key moments during this process (initiation of the explosive atmosphere, membrane rupture).

Collection of explosion overpressure data will be ensured by placing pressure sensors in holes in the upper polycarbonate plate, with the collected data transmitted via an amplifier to the computing unit for analysis.

A sparking electrical system will have electrodes placed in the explosion chamber at the center of the spiral. To verify the model's resistance to overpressures generated by the air-hydrogen mixture, the prototype's geometry has been accurately replicated in a virtual environment (see Figure 1).



a) b)

Figure 2. Projected geometry a) and virtual geometry b)

The computerized simulation of the air-hydrogen mixture was carried out in two stages:

- The first stage focused on the explosion process and considered only the fluid volume of the prototype, recording the pressure values on the surfaces of the delimiting walls and the maximum overpressure value recorded in the cells set with an explosive atmosphere. The membranes between the cells were removed (open surfaces), with the cells being delimited only by the support frames of the membranes. The simulation was performed in ANSYS Fluent;

- The second stage of the simulation consisted of taking the data obtained in the first stage, namely the pressure values on the wall surfaces, and applying them to the surfaces of the solid bodies (the contact surfaces between fluids and solids). The simulation was performed in ANSYS Transient Structural.

First stage - Initial explosion settings in the fluid medium:
Cells set with explosive atmosphere: 1, 2, 3, and 4, starting with the cell in the center of the spiral; Hydrogen concentration in the air: 20% vol.; Temperature: 20°C; Pressure: 101325 Pa; Initiation point: cell 1, in the center of the spiral.

Results: The maximum pressure recorded inside the volume of the 4 cells reached a value of 351119 Pa, at t = 0.0044 s (Figure 3).

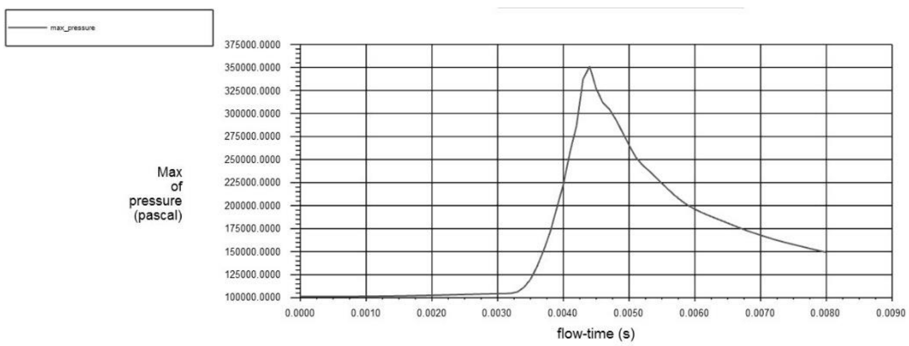
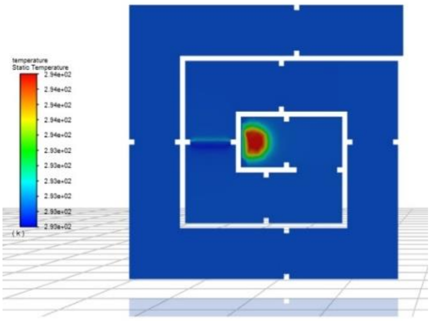
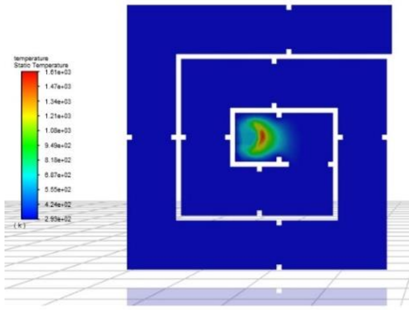


Figure 3. The evolution of the pressure values inside cells 1 - 4

The behavior of the flame front, represented by colored contours of temperatures, is shown in the sequence of images in Figure 4.:





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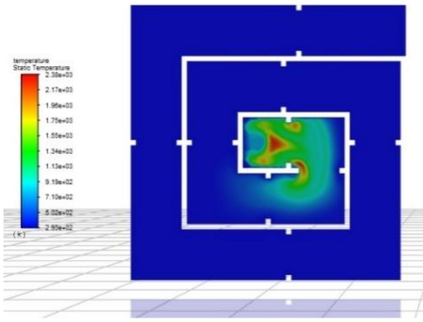
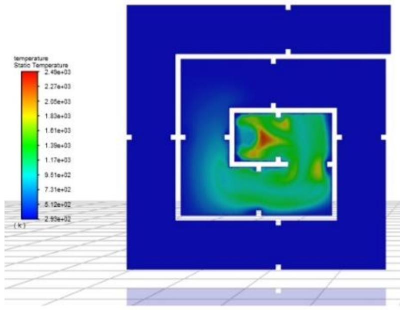
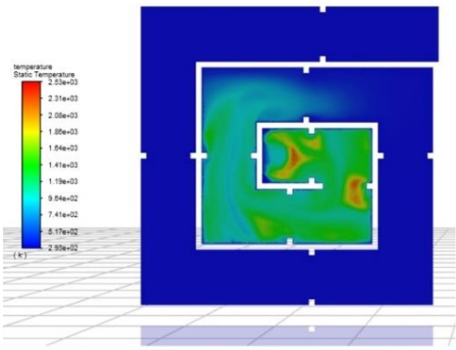
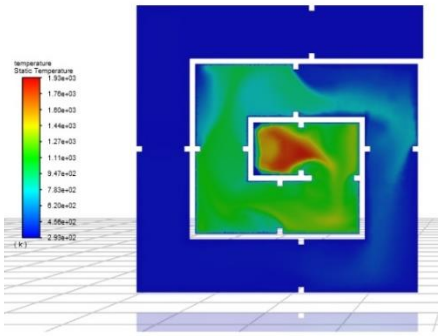




c) d)

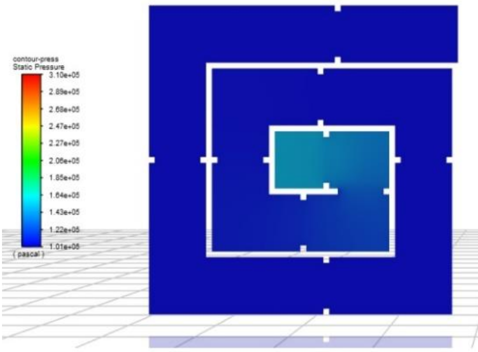




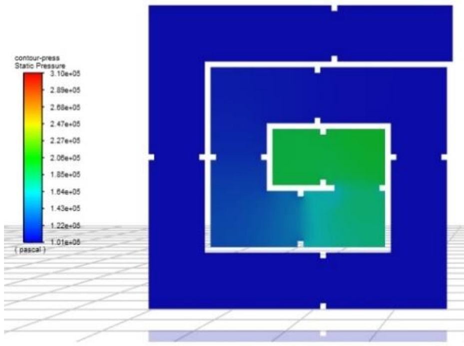
e) f)

Figure 4. Sequence of images with colored contours of temperatures.

The evolution of the pressure values is shown in the sequence of images in Figure 5, through colored contours:



a)



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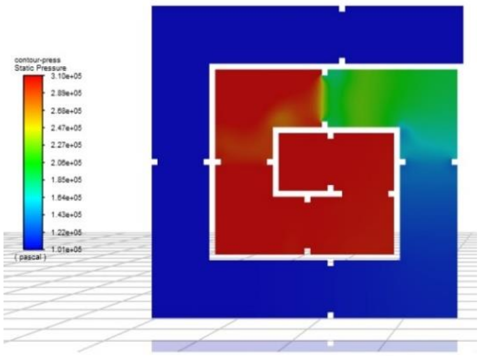
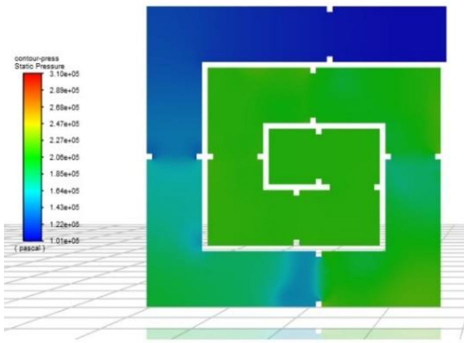


c)



d)

Figure 5. Sequence of images with colored contours of pressures.

The second stage:

The pressure values obtained in ANSYS Fluent during the first stage of the simulation, corresponding to the walls of the fluid volume, were transferred to ANSYS Transient Structural and applied to the solid bodies on the contact surfaces between them and the fluid volume (Figure 6). The top cover was intentionally hidden to allow observation of the pressure application on the interior surfaces.

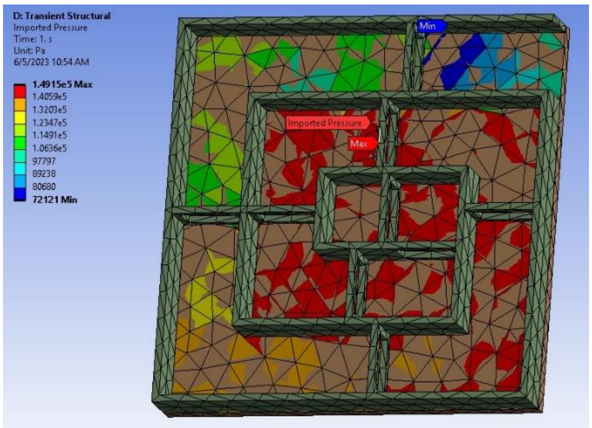


Figure 6. Colored contour of the pressure values applied on the surfaces of the solid bodies.

The metallic spiral was assigned the material Structural Steel from the program's database. The two plates - upper and lower - were defined with a thickness of 10 mm, with the following characteristics: Density: 1200 kg/m³; Maximum tensile strength: 6E+07 Pa; Yield strength: 5.5E+07 Pa.

The pressing of the polycarbonate plates onto the metal spiral was simulated using 4 surfaces placed at the corners of each plate (Fixed Support), acting as 4 fixing/clamping points for the plates.

Results: Following the initiation of the explosive mixture, amid the pressure increase highlighted in the graph in Figure 2, the solid model shows a maximum deformation of 0.157 mm on the surface of the upper plate, at t = 0.0042 s (Figure 7).

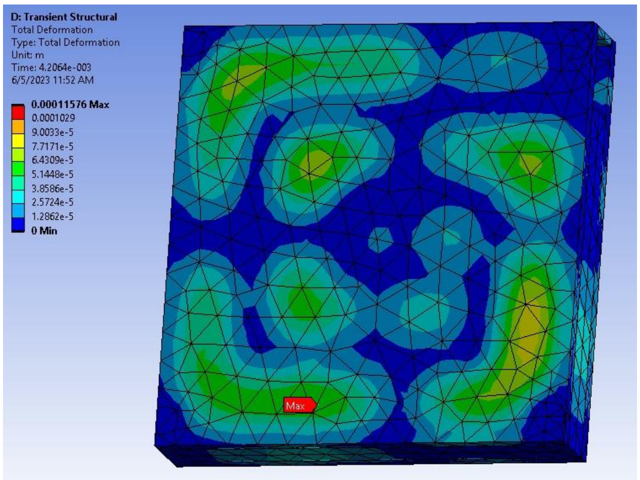


Figure 7. Colored contour plots of the deformations of the polycarbonate plates, highlighting the maximum value

It should be noted that the computerized simulation presented in this phase of the project aims to approximate the overpressure values generated by the air-hydrogen explosion. [3]The results have not been validated based on physical experiments conducted on the same geometry. However, the set of values obtained provides a reference point for the designer in sizing the polycarbonate plates and assembling the experimental model.

2.3 The development and instrumentation of the experimental model for analyzing the development of explosions in air-hydrogen mixtures, including the modification of propagation direction.

Based on the results of the previous stage of the project, which involved computer simulations of air-hydrogen mixture explosions, polycarbonate sheets with a thickness of 20 mm were selected as the construction material for the experimental model. This choice was made due to polycarbonate's properties of transparency and superior resistance to shocks and high pressures. Ensuring safety during experiments, the internal cross-section of the explosion tunnel was set at dimensions of 50 x 30 mm.

With these parameters established, the only constraint was imposed by the diameter of the parabolic mirrors used in Schlieren techniques for recording. [4] Consequently, around the ignition chamber (which contains the source for initiating the explosive mixture), a spiral was constructed with 20 mm thick walls and a width of 50 mm, extending to the endpoint of a circle section with a diameter of 412 mm (the diameter of the parabolic mirrors) – Figure 8. This resulted in a length of the spiral's centerline of 1040 mm and an internal volume of 1.56 liters.

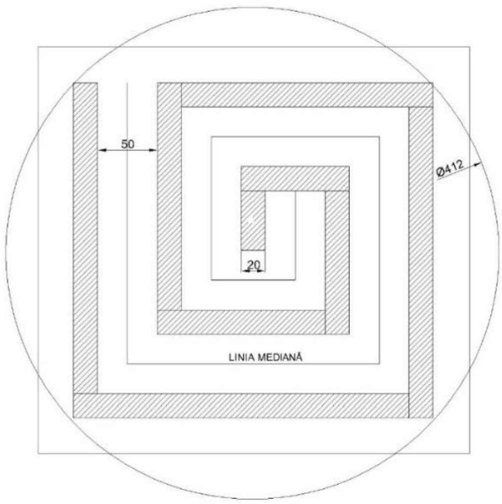
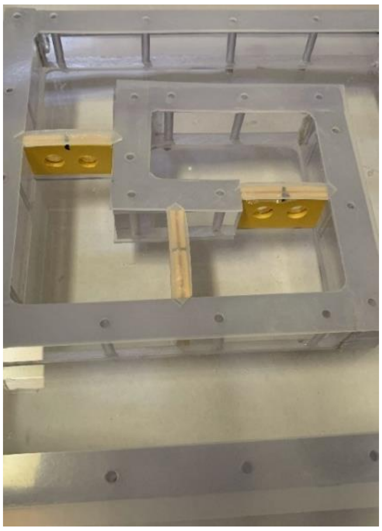
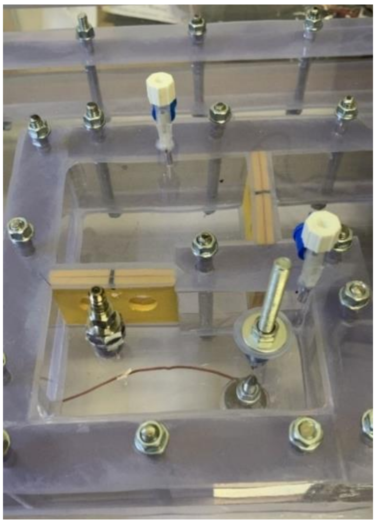


Figure 8. Construction sketch of the experimental model for analyzing the development of air-hydrogen mixture explosions, with modification of the propagation direction

To seal the spiral on the upper and lower closing plates of the model, gaskets were fabricated. Additionally, at various distances along the centerline, three rectangular baffles were made and installed. Each baffle consists of two plates with two 12 mm diameter holes, separated by food-grade film to divide the spiral tunnel into distinct chambers (Figure 9a).



a.



b.

Figure 9. The installation of the gaskets and the three baffles (a), and the equipping of the initiation chamber with electrodes, pressure sensor, and hydrogen introduction device (b).

The first chamber, for initiating the air-hydrogen mixture, was equipped with electrodes for generating electrical sparks, a capped device for hydrogen introduction, and a pressure sensor (Figure 9b). The other two sealed chambers were equipped only with fuel gas charging devices. [5] The remainder of the spiral path was intentionally left open to release explosion overpressures. The final model is presented in Figure 10.

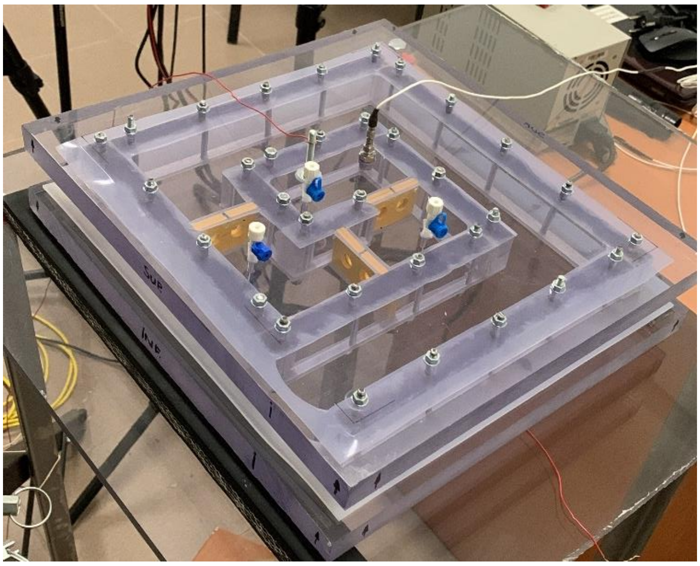


Figure 10. The experimental model for analyzing the development of air-hydrogen mixture explosions, with modification of the propagation direction

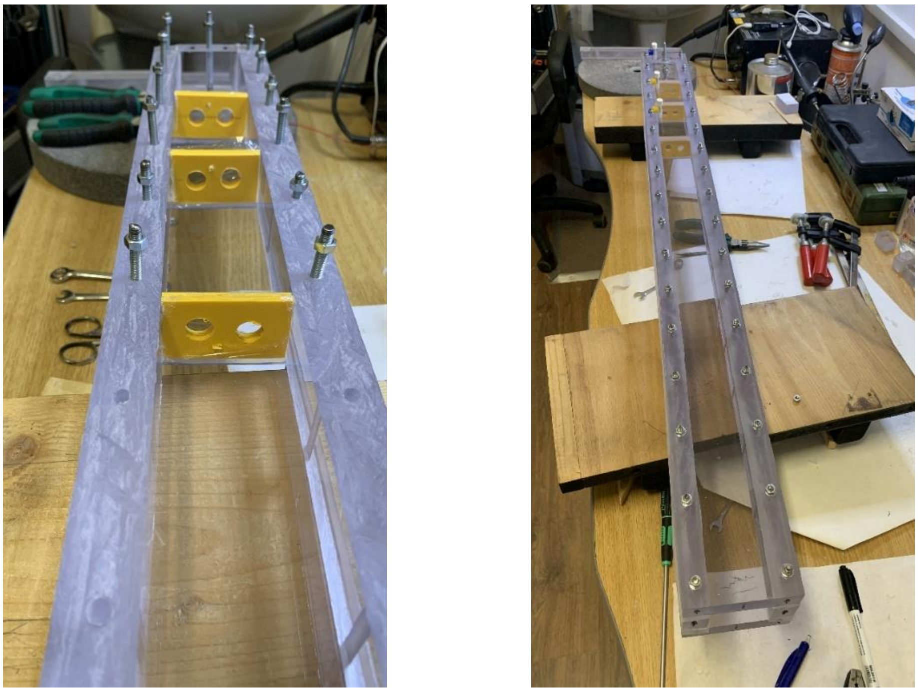
2.4 The development and instrumentation of the experimental model for analyzing the linear propagation of explosions caused by air-hydrogen mixtures

For the comparative analysis in the subsequent stages of the project, focusing on hydrogen explosions with linear propagation and directional change, there is a need for equivalence between the two experimental models. This includes the explosion propagation section, tunnel path length, volumes of chambers separated by baffles (baffles placed at the same distance along the centerline from the sealed end), placement distances of pressure sensors and electrodes from the sealed end, and importantly, the concentrations of combustible gas used in the physical experiments.

Therefore, the experimental model for analyzing the linear propagation of air-hydrogen mixture explosions (Figure 11) was constructed to match the length of the centerline of the experimental model used for analyzing the development of air-hydrogen mixture explosions with directional change, which is 1040 mm. The explosion tunnel section measures 50 x 30 mm.

The electrodes for initiating the explosive mixture through electrical sparks, the pressure sensor, and the three baffles were positioned at the same distances from the sealed end of the model as in the spiral construction, using the centerline as reference.[6]

The construction was sealed with gaskets, both between the side walls and the upper and lower plates, and around the baffles placed along the explosion path.



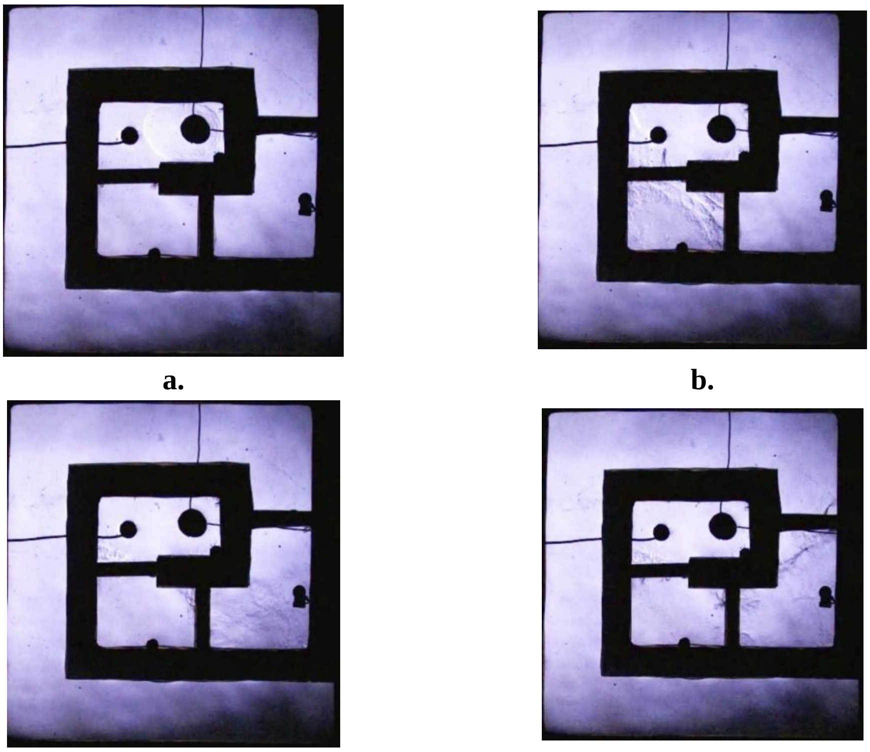
a. b.

Figure 11. Aspect during the construction of the experimental model for analyzing the linear propagation of air-hydrogen mixture explosions (a) and its completion (b)

2.5 Testing the functionality of the experimental models

For testing the functionality of the experimental models, they were integrated into a recording system using Schlieren techniques capable of highlighting density gradients at the interface between burnt gases and those ahead of the flame front during rapid combustion processes.[7]

In both cases (the spiral and linear models), a concentration of 20% vol hydrogen in air was used to charge the three chambers separated by the previously described baffles with foil-covered holes. The first chamber (initiation chamber) of each model was equipped with a pressure sensor, with values recorded and assisted by a computer. The volumes of the three chambers were 157.5 ml (chamber 1), 138 ml (chamber 2), and 193.5 ml (chamber 3), while the rest of the explosion path remained open to clean air. Video recordings were conducted using a high-speed Phantom camera at a frequency of 30,000 frames per second. The results for the spiral model highlighted the initiation and development of the air-hydrogen mixture explosion, as well as the propagation of the flame front through the three chambers (breaking through the foil barriers), the passage of the flame front into the space beyond the baffles, and its extinguishment once the combustible support was consumed (Figure 12 a-d).

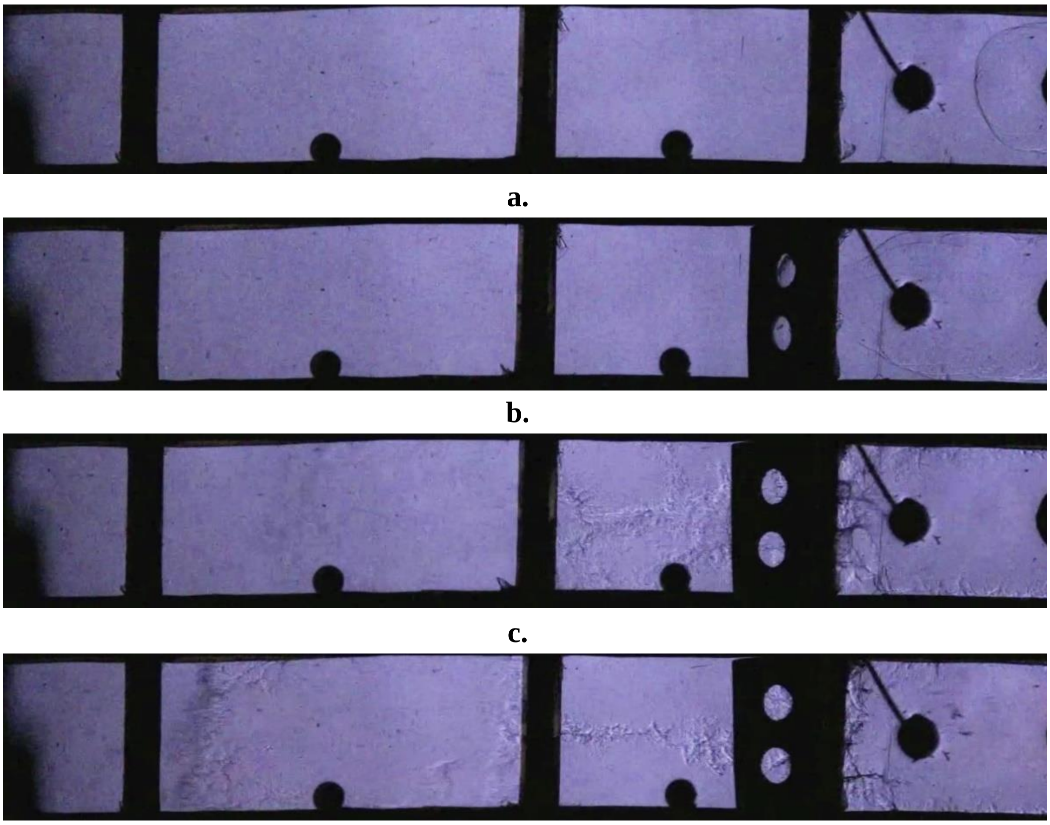


a. **b.**

c. **d.**

Figure 12. Aspects of the explosion development at the level of the experimental model for analyzing the development of air-hydrogen mixture explosions, with directional propagation modification.

In the case of the linear model, the process unfolded relatively similarly to the first case, with the distinction that the first baffle was dynamically more affected compared to the spiral model. Throughout this experiment, the flame front traversed all three chambers, breaking through the foil barriers and extinguishing upon the depletion of the combustible gas (Figure 13 a-d).



a.

b.

c.

d.

Figure 13. Aspects of the explosion development at the level of the experimental model for analyzing the linear propagation of explosions caused by air-hydrogen mixtures

Regarding the explosion pressures, they differ between the two cases, with the linear model recording a peak of 3.82 bar and the spiral model recording a peak of 3.04 bar, these values being measured at the level of the second chambers (Figure 14).

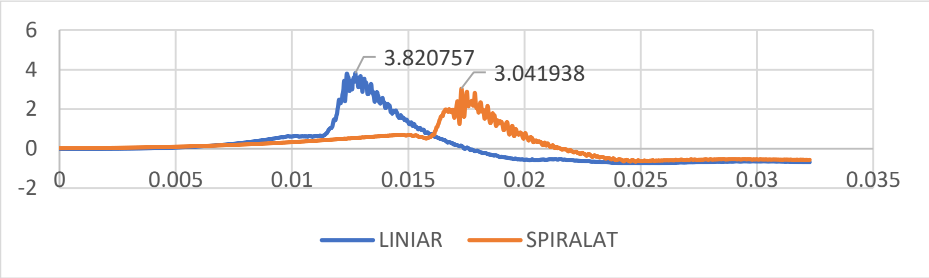


Figure 14. Graphs of the pressure values recorded on the two experimental models

3. RESULTS

Following the physical experiments of air-hydrogen explosions on the two models – linear and spiral – it was found that the selection of construction materials and the assembly method of the elements was well-founded, with the experiments proceeding safely. No cracks, fractures, or displacements were detected in the structural integrity of the models. The movement of the baffles represents predicted dynamic effects, typically generated by explosion overpressures.

Thus, the conducted experiments demonstrate the functionality of both experimental models, both in terms of recording explosion pressures and visualizing and recording the behavior of the flame front, as well as ensuring operational safety.

4. CONCLUSIONS

Virtual testing proved to be highly effective in the initial phase of transitioning from methane to hydrogen explosion studies.These tests enabled researchers to understand the aggressive explosive characteristics of hydrogen without the immediate risks associated with physical testing.

Thus, the results from virtual tests were crucial in selecting appropriate materials and configuring the experimental models. These helped in accurately sizing the models, ensuring they met the required safety standards and experimental objectives. Conducting virtual tests prior to physical experiments ensured that safety requirements were thoroughly addressed, reducing potential hazards. This approach allowed for the fine-tuning of experimental designs, optimizing them for accurate and reliable physical testing.[8]

The correlation between virtual simulations and physical test results demonstrated a high degree of accuracy of the virtual models which has effectively predicted explosion pressures and flame front behaviors, which were later confirmed in physical experiments.

This validation highlights the reliability of virtual testing as a precursor to real-world experimentation. Moreover, virtual tests enabled the exploration of both linear and non-linear trajectories in hydrogen explosions, providing a comprehensive understanding of explosion dynamics. The consistency between virtual and physical models facilitated comparative studies, enriching the knowledge base and informing better safety and engineering practices.[9]

In conclusion, virtual testing has proven to be a crucial and effective step in the development of physical experimental stands for hydrogen explosions. It has ensured safety, guided accurate model development, and provided reliable predictions that align closely with physical test results. This approach enhances the overall understanding of hydrogen explosion dynamics and contributes to the advancement of safety standards and engineering practices.

Acknowledgements

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RESEARCH ON THE MEANS OF IMPROVING THE TIMES OF LOCATING AND EVACUATING VICTIMS IN INTERVENTION AND RESCUE ACTIONS

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Abstract: *In the industrial areas likely to generate toxic/explosive atmospheres, a trend is observed for retrofitting with compact installations, often very close, very small free spaces, the structures where the equipment and production lines are mounted are often metal load-bearing structures, closed with metal panels thermal insulation, due to the economic advantages regarding both construction and energy costs during use. Disadvantages to the traditional construction concept of industrial premises, the use of concrete constructions and more "airy" production lines, present a challenge for rescue teams in the event of an explosion or fire with massive smoke emissions. Considering the priority of rescuing people caught by the event, the high probability of their intoxication, the rapid location of people who could not self-evacuate is a battle against time. Rescuers participating in such interventions need locating equipment capable of operating in a space that largely blocks radio waves through a shielding effect, while at the same time allowing for high mobility, low weight and volume, characteristics necessary for creeping through spaces limited free spaces and ensuring a low consumption of compressed air, if the atmosphere has become unbreathable.*

Key words: *rescuer, team, toxic, atmosphere*

1 INTRODUCTION

During the intervention, the rescue teams face a number of logistical challenges and must manage very well the influence of each factor on the way the action is carried out. If the atmosphere in the working environment is affected by the appearance of gases or smoke, the use of protective devices involves managing the air reserve and evacuating the affected area when this is required by the air reserve [1]. Obstruction of access ways, freeing the injured from under various structures often require a large volume of work and implicitly compressed air. Technological progress nowadays allows the use of light, compact equipment with a major impact on the duration of the intervention but also on the consumption of compressed air by reducing the physical effort of the rescuers [2].

In order to locate the missing persons as precisely as possible, compact search kits such as the ***Savox Disaster Deployment Kit*** (fig 1), intended for professional use

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by search and rescue teams, can be used. It provides tools for visual search and location of victims, as well as life detection through seismic and acoustic sensors. The equipment is stored in a single carrying bag and can be quickly moved to where it is needed due to its low size and weight [3],[5]. The kit includes the complete Delsar Life Detector system with six sensors that provide seismic detection of victims and the Search Cam 3000 with the telescopic extension tube kit, which allows a range of up to 5.6 m. Alternatively, the camera can be used without the tube set and lowered into a cavity using the rope accessory kit provided. The camera head is waterproof to a depth of 23m.

Figure 1 Savox Disaster Deployment Kit

The camera is equipped with a video sensor in the visible spectrum and IR, around the lens there is a matrix of 16 white light LEDs with adjustable illumination level that ensures visibility of 6m in total darkness, the camera angle is very wide, 280°, for the use of the camera requires a minimum access diameter of approximately 5 cm. The camera can be pivoted from the gun console by operating the 240° angle motor controls, a microphone and speaker are provided in the camera housing to ensure two-way communication with the trapped persons. For ease of use, a 5.75-inch ClearSearch trans-reflective LCD monitor is also mounted on the gun console. To locate trapped people in a premises where there is no longer access as a result of partial or total collapse, the six seismic sensors are placed around the construction and by using two frequency ranges in the range of 1-3000 Hz, and noise filtering background, the signal level of the six channels is monitored on the screen (fig. 2). The operator of the device has a spatial image of the entire volume in which the search is made and based on the intensity of the received signals can estimate the probable location where the trapped persons are located. Seismic sensors are provided with magnetic fixing elements for fixing on metal structures or metal stake for fixing in the ground, depending on the situation in the field the desired fixing system is chosen.

Figure 2 The screen of the Life detector device with signal from three seismic sensors

The device also contains an acoustic sensor in a sealed housing, the sensitivity of the sensor is between 80 and 4500 Hz, by mounting it on the telescopic rod it can be inserted into openings of at least 4.5 cm, the 10 m connecting cable allows the detection of noises at a great distance from the outside collapsed area.

The RD-400 Radar Detector (fig 3) is a portable radio detection system designed to locate survivors buried under rubble or debris by either movement or breathing. The RD-400 is based on ground-penetrating radar (GPR) technology, which allows it to pinpoint the location of a survivor and determine the distance to it. The device is very simple to operate. It starts with the push of a button, sending GPR signals into the scanned structure, quickly detecting any movement or breathing. The tablet displays the distance to the survivor using a red icon for movement and a blue icon for breathing (fig4). By moving the bag over the entire structure, the affected building is scanned and survivors are located. The settings available to the user allow the choice of the material to be searched according to the medium the waves need to penetrate, such as concrete, snow, air, etc. Localization in the case of reinforced concrete structures with a thickness of 40 cm can be done up to 16 m based on the motion sensor and 10 m for the breathing sensor. The device works autonomously with its own batteries for 12 hours, has a mass of 10.5 Kg, dimensions are 49x20x40 cm. The working frequency is 400 MHz, for high precision the sensitivity of the device can be changed in 8 steps, additionally the analysis time can be changed in fixed steps of 15, 30, 60 and 120 seconds depending on the difficulty of the environmental conditions. The tablet connects to the unit via wifi, the maximum distance at which the connection works is 100m. The maximum distance of interest can also be selected from the graphical interface, limiting the scanning depth in fixed steps to 3, 7, 15 and 30m. The transmitter signals are received by a 120-degree angle sensor, thus covering a large area with each transmission-reception cycle.

Figure 3 Radar Detector RD-400

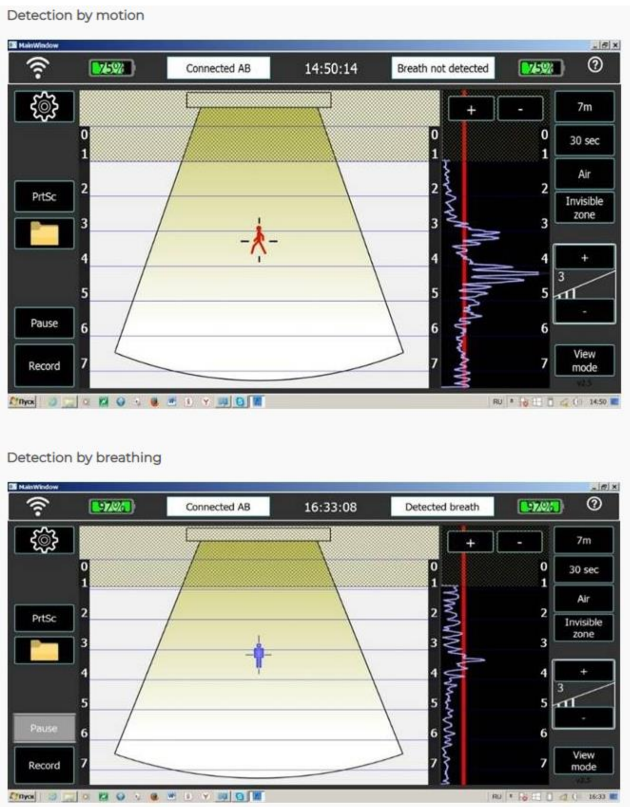

Figure 4 dual search mode, with motion and breathing Sensors

When the rescue team may be faced with large areas of damaged buildings or structures, when data on the number and location of people remaining in the affected area is not precisely known, it is useful for the rescue teams to be able to use equipment capable of processing a lot of information simultaneously, to install it quickly and to cover very large areas [4]. One such piece of equipment is the ***Leader multisearch***, a kit that includes 5 different search tools connected to a single control unit (multi app box fig 5).

Figure 5 multi app box view information from different type search sensors

The central unit can retrieve and display information from the video camera in the visible spectrum (fig 6), from the thermal camera (fig 7), from seismic sensors and from the radar sensor that scans through materials.

Figure 6 visible spectrum chamera

Figure 7 thermal chamera

The use of the cameras is done by mounting them on the telescopic arm gun mount on which the multi ap box can also be mounted, or if the team finds it more useful to have one person monitor the information provided by the sensors and another person operate the camera, they can be separate. The telescopic arm is 2.4 m long in extended mode, the video camera has its own illumination adjustable in 8 steps, it has a microphone and speaker for two-way communication. When using a video camera, the multi app box prioritizes the information from it giving the largest space on the screen to the video image, the rest of the information coming from other sensors is displayed in the form of icons. The controller on the gun handle can rotate the camera around its axis 260 degrees to explore large areas. If in the room where the rescuers suspect the casualty is, there are obstacles or structures obstructing the video camera in the visible spectrum, it can change the camera to a thermal one, which can scan thermal radiation in the range of 0-120^{0}C. The camera is designed to be used in harsh environments, has high protection against scratching the thermal sensor, can be used underwater up to 2m deep and is protected with a membrane to absorb shocks and protect the camera's rotation mechanism. In order to always have a clear image of the angle in which the camera is positioned with respect to the axis of the telescopic arm, the position of the camera is permanently shown on the display of the multi app box. The optical angle of the camera is 226 degrees and the left-right control on the gun allows the camera to be oriented at 850 left and right respectively.

For the probable location of people, three seismic sensors (fig 8) with wireless connection can be used. The communication radius is up to 100m in an unobstructed field. The sensors can be activated very quickly after installation. Information from sensors can be filtered against background noise that may occur during search activity, made by vehicle, pneumatic or electrical equipment.

Figure 8 wireless seismic sensors

Surveying a collapsed structure can be done with a wideband scanning sensor (also called a "seismic/acoustic instrument") designed to detect and locate survivors buried under structures by detecting movements. The SCAN Ground Penetrating Radar (fig 9) features Ultra Wide Band (UWB) technology that scans the debris surface to search for the movements of conscious or unconscious victims up to 30m unobstructed. This radar detects most movements of a conscious or unconscious person through 50 cm of concrete, wood, tiles, glass, plaster, bricks, sand, sandstone, bitumen, plastics, etc. The radar antenna and associated electronics are mounted in a small, waterproof and shockproof housing. It has an exchangeable Lithium-Ion battery, giving it 4 hours of operation in the field. A battery level indicator can be seen on the outside of the sensor to avoid opening it in the field. The SCAN victim detector is connected to WiFi with a range of 30 m, which makes it easier to maneuver in the field, but can also be connected by cable if interference occurs.

Figure 9 UWB band SCAN radar

2. CONCLUSION

1. The rescue activity requires a quick and effective intervention.
2. When the main activity of the rescue teams is to locate and save people surprised by the dynamic effects of an explosion on the structural elements of buildings or installations, the success of the activity depends to a large extent on the type of equipment that the team has at hand.
3. Low weight portable equipment using batteries and wireless connectivity are easier to deploy in the field and offer reduced installation times
4. In the industrial environment with the risk of explosion or fire events, the existence of rescue stations manned by personnel from production facilities offers the advantage of intervening with appropriate equipment to rescue workers caught by the event because the staff knows the affected facility best and the equipment that can be used for the intervention.
5. The variety of intervention equipment for events such as fires and explosions on the market is large, for equipping rescue stations it is useful to evaluate the possible effects produced by fires or explosions on the installations and purchase the right equipment.

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CONSIDERATIONS ON LEVELS OF ANALYSIS OF MINING PROJECTS

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Abstract: *Two levels (types) of analysis are generalized in project appraisal theory: economic and financial. Public projects of an economic nature (to which, for the time being, state-owned mining companies can be assimilated) and large projects (which cannot be financed by private capital alone, as state intervention is necessary) require a third level of analysis. This is the analysis at the level of the national economy, which is no longer limited to the calculation of economic and financial efficiency indicators of the project, but aims to highlight and quantify the overall effects of the project (increase in receipts for the consolidated state budget, relieving the state of certain social obligations, increase in the population's income, increase in employment, improvement in the social situation in certain areas, improvement in the balance of external payments, etc.). Thus, project costs are no longer based on market prices for factors of production (expressed in constant or current currency), but on so-called theoretical or reference prices (obtained by correcting market prices according to assumptions based on certain macroeconomic analyses). Their complex and wide-ranging character is compensated by obtaining relevant results in substantiating decisions on the utilization of the national mineral resource potential.*

Key words: *mining project, evaluation, economic analysis, financial analysis, macroeconomic analysis*

1. INTRODUCTION

An analysis of the development of the mining sector reveals that many mining projects have almost all the characteristics of large-scale projects (unprecedented economic scale, significant mobilization of resources, the need to use complex technologies, financing requirements that may exceed the means of those involved, the induction of significant effects on the economic and social environment in the area where they are carried out, the existence of random aspects and risks difficult to control, the use of sophisticated management techniques, the need for multidisciplinary skills, the existence of long time lags between the different phases, specific strategies of the participants, etc.). Because of their global economic and social implications, the issue of their evaluation is a complex one, which needs to be addressed at different levels, corresponding to certain degrees of knowledge and importance [3].

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The evaluation of investment projects, regardless of their nature, must highlight, on the one hand, the effects on the organizations that carry them out and, on the other hand, the effects on the economic system in which they will be integrated. In countries with a functioning market economy, however, there are only two types of analysis, economic (at the project level) and financial (at the level of sources of financing) [4], with the assumption that the project will be integrated into an economic system capable of linking the interests of private enterprise to those of the national economy. For countries with developing economies (such as Romania), a third type of analysis, at the level of the national economy, is also recommended [1].

2. ECONOMIC ANALYSIS

The economic analysis is both the first level of analysis and the first step in the assessment of a mining project, the purpose of which is to determine whether the project is eligible for inclusion in the portfolio of bankable projects [8]. The analysis is developed at the level of the project itself and aims to highlight the project's ability to be self-financing, i.e. a higher or lower level of profit. As a rule, the elements required for the evaluation, the inflows and outflows, are expressed in terms of constant reference currency values. As a result, the effects of inflation are not taken into account, since it is considered that inflation will affect the prices of both the inputs involved and the outputs of the project. Clearly, if such an assumption does not meet the arguments for confirmation over the whole economic lifetime of the project, the use of certain forecasts for the trend of some prices may become necessary. From the point of view of the costs involved, it is characteristic for this level of analysis not to take into account the so-called financial costs (interest rates on loans contracted) and the costs of various taxes, duties and similar charges.

Also, as far as accounting expenses are concerned, depreciation is not calculated, but the so-called capital depreciation cost is used. In conclusion, relevant for the economic evaluation of a mining project are capital expenditure, operating expenditure, maintenance expenditure and the cost of depreciation of invested capital. With regard to the last category of expenditure, which in fact expresses the opportunity cost of the invested capital, of utmost importance is the choice of the rate on the basis of which the returns to depreciation levies will be determined.

3. FINANCIAL ANALYSIS

Financial analysis is a higher level of evaluation than economic analysis, its fundamental objective being to highlight the profitability of the equity invested in the project [8]. Obviously, only economically feasible projects, i.e. those that have "passed" the first stage of economic analysis, are subject to financial analysis. The characteristic feature of the financial analysis is to take into account the effects of inflation, at least as regards the renewal of depreciable assets characterized by a large difference between the accumulated depreciation calculated on the basis of unrevalued input values and the inflationary prices to be borne at the time of replacement. In order to be able to address the main issues raised by the correct rationale for the financing decision (optimal structure of capital sources, possibilities to cover cash-flow gaps in the operation of the project, verification of self-financing capacity, ensuring the profitability of equity capital in relation to other investment opportunities), analysis at this level requires a detailed investigation of the project's sources of financing. The impact on the cost categories considered is major. Thus, in addition to the costs taken into account in the economic analysis (capital expenditure, operating expenditure, maintenance expenditure), all other costs in the nature of explicit expenditure, actual payments (interest paid on loans taken out, income taxes, taxes on profits, customs duties, other taxes and duties) are also relevant to the financial analysis. In fact, the formation of cash flows at project level is approached from the perspective of financial accounting, standardized and uniformly applied. Compared with the economic valuation, there is still a major difference in the treatment of the capital invested in depreciable assets, due precisely to the accounting perspective. Thus the cost of depreciation of invested capital (a cost of an economic nature) is replaced by book depreciation, calculated in accordance with tax legislation.

4. MACROECONOMIC ANALYSIS

All the particularities presented above, as well as the current economic and financial situation of Romanian mining companies (in fact, of the mining sector as a whole), make it necessary to transfer the problem of evaluating mining projects of national importance from the microeconomic to the macroeconomic level. The economic-financial feasibility of such projects should not and cannot be assessed solely on the basis of indicators specific to the microeconomic level, but also requires consideration of macroeconomic aggregate magnitudes [7]. Only in this way can the effects induced by these projects on the national economy be highlighted, as reflected in the flows of goods, services and money between the mining sector and the other sectors of the economy, and between the mining sector and the state budgets.

The effects method was originally designed for developing countries. In times of crisis, even in developed countries, there has been a significant underutilization of various categories of labour force (unemployment), underutilization of production capacities and a significant dependence on foreign trade (but not in the sense that, under globalization, trade flows have gone beyond national borders, becoming a reality of the world economy).

It is quite obvious that Romania, categorized as a developing country, is acutely characterized by the above: unemployment, underutilization of production capacities and dependence on foreign trade. This is why the evaluation of mining projects of national importance (projects to continue activity through modernization, reconstruction and development or new development projects) will no longer be able to avoid applying the effects method.

Applying the effects method involves four stages: presenting the project in general; analysing the financial profitability of the project; drawing up an economic appraisal study comparing two alternatives for satisfying the same domestic demand: the "with project" alternative and the "without project" alternative; and drawing conclusions on the project evaluation using the effects method.

The general presentation of the project must be technical and economic. The technical aspect shall consider: deposit conditions, reserves of useful mineral substances, their quality, possibilities of extending reserves, necessary open-pit mining works, mining methods, mining technologies, preparation technologies. The economic aspect covers information on: required capital expenditures and their phasing, annual operating and maintenance expenditures, annual gross revenues from the sale of mineral production, economic life of the project. Particular attention must be paid to the structure of operating and maintenance expenditure in order to be able to correctly identify the uses to which the cash flows constituting it are put. Gross annual revenues are estimated taking into account the quality of the production realized and the market for mineral raw materials.

In analysing the financial profitability of the project, the alternative of importing the useful mineral substance will be considered. It will be assumed that the project will provide the domestic market with a mineral raw material of the same quality and at the same price as if imports were used. Also, for the future mining enterprise (realized by the project), the payments to the management and departments will not be considered as costs, as they will be assimilated to internal transfers from the enterprise to the branch. The basic indicator for assessing the financial feasibility of the project is the gross operating result rate, calculated as the percentage ratio between the annual gross operating result and the investment required to carry out the project. The project's internal rate of return and the (discounted) payback period can also be established.

The economic evaluation of the project is a five-step process:

- precise definition of equivalent situations in terms of satisfying the internal demand from the production that the project either realizes (the "with-project" alternative) or does not realize (the "without-project" alternative);
- analysis of the "with project" alternative in terms of induced expenditure; to carry out this analysis it is necessary to have economic information both on the project itself (the structure of consumption, reflected in the structure of capital expenditure and operating and maintenance expenditure) and on the whole economic system into which it is to be integrated (input-output table or balance of links between branches);
- analysis, in the same terms, of the "without project" alternative;
- comparison of the "with-project" alternative with the "without-project" alternative in order to highlight the net effects of the project on the national economy;
- presentation, in the form of indicators, of the effects that the project will have on the economy (on this basis, it will be possible to assess the interest of the project for the national economy).

The analysis of the two alternatives, 'with project' and 'without project', involves first of all identifying the main expenditure-generating activities in each of the two alternatives. The total amount of this expenditure is then disaggregated to show how much of the total amount of expenditure is accounted for by domestic consumption and how much by imports. Since the table showing the structure of intermediate consumption is available, domestic consumption is also analysed: how much of it was domestic and how much imported. In this way, the fundamental indicator on the basis of which the two project alternatives will be compared, i.e. "value added", can finally be highlighted.

Such an overall comparison considers, for each alternative, the effects on:

- population income and its distribution throughout the country, as a result of the salaries paid to employed staff;
- the State budget and the State social security budget, through the taxes transferred and their possible payment burdens (e.g. unemployment benefits, if one of the alternatives, the "without project", implies the dismissal of employed staff or the non-employment of already unemployed people);
- jobs in economic sectors upstream and downstream of the mining sector;
- additional regional income;
- volume and dynamics of investments in the mining and other industries;
- production of other industries;
- foreign trade, external balance of payments and foreign exchange reserves of the country.

The application of the effects method concludes with the presentation of the conclusions, in which the superiority of one of the two alternatives, in relation to the possibilities and needs of the national economy, must be highlighted, concretized in a synthetic indicator, represented either by the value added rate (calculated as the percentage ratio between the annual value added and the total investment) or by the additional value added (calculated as the difference between the annual value added of the two alternatives, "with project" and "without project").

5. CONCLUSIONS

The diversity of the calculations involved in the application of the effects method simply reflects the diversity of the objectives pursued and the existing constraints. However, this diversity can be structured around two main poles:

- the "national economy" pole, where will be found the overall economic calculation and partial calculations of different aspects related to national level objectives and constraints (economic growth, budget balance, unemployment/jobs, increase in general welfare);
- the "enterprise" pole, where the financial calculations of profitability will be found, taking into account the constraint reflecting the necessary financial equilibrium of the enterprise.

With regard to these calculations, two aspects are worth noting.

From the outset, it should be clear that there is no a priori reason why it is necessary to obtain concordant results by carrying them out. It is obvious that these calculations are based on different rationales: the former are based on 'plan' rationales, with their own restrictions and objectives, and the latter, concerning the undertaking, on 'market' rationales. The possible contradiction between the two types of calculation merely reflects, at the project level, the contradiction between the two rationales: the 'plan' and the 'market'. It is not possible to make a synthetic calculation which aims, ex ante, to reduce this contradiction. Such an attempt will only mask the contradiction and not eliminate it. But this is precisely the role of the method, which is to highlight this contradiction at the economic evaluation stage, i.e. to assess the economic policy (tax, customs, credit, subsidy, etc.) that is capable of bringing the two types of calculation to comparable results.

The second point is that evaluation by 'national economy' calculations cannot be reduced ex ante to a single overall economic calculation. The diversity of such calculations simply reflects the diversity of objectives pursued and constraints encountered in the national economy when considering the allocation of scarce state budget resources differentially across different branches of the domestic economy.

Even though it requires extensive calculations and a significant amount of information on the project under evaluation (e.g. coefficients of intermediate consumption between branches), we believe that the use of the effects method in the evaluation of mining projects of national importance is necessary, because only in this way can a judicious allocation of state resources be achieved, while highlighting for each project the multiple effects on the income of the employed labor force, available employment, state resources, activities and demand in the different branches of the national economy, and regional development of the country.

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CHALLENGES AND LIMITS OF THE TRANSITION OF ROMANIAN MINING SECTOR TOWARDS A CIRCULAR ECONOMY

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Abstract: *Starting from the role that the circular economy plays in achieving the economic development goals agreed by the European Union while protecting the environment, this article argues the importance of this concept, which is in full evolution in a sector considered one of the largest generators of waste. Thus, the principles of the circular economy can be extended to the mining sector, offering a viable solution to the limitations of the linear economic model. In a linear model, resources are extracted, utilized and disposed of, generating waste and significant environmental impacts. In contrast, the circular economy promotes a regenerative system, where materials and resources are kept in use for as long as possible, reducing over-extraction and waste. But the transition to a circular economy is a complex task, all the more so as we are talking about an industry based on the extraction of primary resources, somewhat at odds with the circular economy concept that advocates a reduction in the need for extraction and processing of new resources in favor of closed-loop systems based on a secondary material flow. Moreover, the sector can adopt a similar logic to that of the circular economy to improve its sustainability performance, through concerns focused on developing innovative processes to utilize and generate value from mining waste.*

Key words: *mining industry, circular economy, linear model, transition, waste generator*

1. INTRODUCTION

The resources used in an economy directly influence its ability to ensure sustainable development. From the extraction of natural resources, essential for production and consumption activities, to the management of environmental impacts through waste disposal and emissions, each step has significant implications for economic and environmental sustainability.

The efficient management of mineral resources, in particular, plays a strategic role in securing the long-term supply of raw materials. This approach not only supports national economic activity, but also contributes to reducing import dependency, thus underpinning economic security.

At the same time, sustainable use of natural resources reduces pressure on ecosystems and contributes to maintaining ecological balance. By adopting efficient practices such as recycling, the circular economy and environmentally friendly technologies, losses and negative impacts on the environment can be minimized.

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Thus, integrating sustainable natural resource management strategies into economic policies is crucial to create the conditions for long-term economic development while respecting environmental protection requirements and ensuring the well-being of future generations.

But the use of resources and the generation and management of waste differs according to the specificities of each industrial sector. The mining industry in Romania and beyond continues to face numerous challenges due to its potential impact on the environment. These challenges are becoming increasingly difficult to overcome with growing social awareness or governmental pressure, requiring a new, more creative approach to resource management and waste utilization.

Under these circumstances the question becomes natural: Can the principles of the circular economy and the mining sector be applied? And this question comes at a time when many economic sectors are finding it difficult to adopt the values of the circular economy due to the particularities of products, their value chains and environmental impacts. Scientific research that has addressed this topic has emphasized that the development of the circular economy concept for the mining sector could address the challenges of environmental pollution, increasing demand and scarcity of mineral resources, the need to manage natural resource wastes in a sustainable way with subsequent economic returns [1; 6; 21] At the same time Lebre and Golev, advocate that the mining industry should embrace circular economy to improve its sustainability performance and create value to become more sustainable and environmentally responsible. [5; 10]. Golev et al. considers that the adoption of circular economy concepts in the mining sector has been realized to a relatively low degree, starting from the fact that the mining sector is traditionally represented by linear rather than circular activities with a role of providing resources to society.[5]

As a result, it is considered that opportunities related to the application of circular economy thinking in the mining sector are linked to the possibility of adopting an economic model, which promotes the careful and sustainable use of natural resources, with the main aim of protecting the environment, reducing negative impacts on ecosystems and increasing economic efficiency.

2. BRIEF REVIEW OF THE SCIENTIFIC LITERATURE ON THE CIRCULAR ECONOMY

In the current context of climate change, increasing demand for natural resources and environmental degradation, the transition to a circular economy has become a global necessity. This approach supports maintaining the value of products, materials and resources in the economy for as long as possible, thereby reducing waste generation and the pressure on the limited natural resources facing our planet. Thus, the move towards a circular economy has entered the agenda of public authorities while attracting the attention of business, research institutes and non-governmental organizations around the world, becoming a strategic priority worldwide.

Although the circular economy concept emerged more than half a century ago, it was not immediately adopted as a global priority. The idea of regenerative design, introduced by Lyle in the 1970s, was rooted in the energy crisis of that period, putting sustainability at the forefront. Later, Pearce and Turner (1990) brought to the fore a critique of the linear economic model, promoting the circular economy as a viable alternative [19].

The concept has gradually developed, gaining increasing popularity amid globalization and economic and environmental crises that highlight the limitations of the traditional consumption and production model. The active involvement of all stakeholders has contributed to the integration of this model into international economic and environmental policies.

There are quite a few critical voices arguing that this concept means different things to different people, appearing to be a collection of semi-scientific ideas and concepts from several fields [7-8].

According to the study coordinated by Kirchherr, the concept of circular economy was analyzed and detailed by comparing more than 100 definitions, each offering different perspectives and emphases. These definitions were grouped around key concepts, which highlight the complexity and multidimensionality of the circular economy, such as [7]:

- Sustainable development,
- the 4R (Reduce, Reuse; Remanufacture, Recycle);
- holistic approach on the three levels (*Micro*: At the level of products, companies and consumers; *Meso*: Through the development of eco-industrial parks, where waste from one process becomes a resource for another; *Macro*: At the level of cities, regions and nations, facilitating the implementation of circular economy strategies in public policies and urban planning);
- The waste hierarchy.

Furthermore, Kirchherr et al. consider that the circular economy pursues economic prosperity as its primary goal, followed by improved air quality, both of which directly impact the well-being of present and future generations by ensuring an equitable distribution of economic benefits and protecting common resources [7].

The circular economy has been recognized as a promising solution to address complex global problems, including natural resource management, waste reduction and environmental protection. Bonciu argues that this economic model represents a comprehensive solution to the challenges facing Europe and the world [2]. This idea is also supported by the Ellen MacArthur Foundation, which describes the circular economy (CE) as "an industrial economy that is regenerative or restorative by intention and design" [3].

The principles of the circular economy are complementary to other sustainable visions that emphasize reducing environmental impacts and responsible resource use, such as the green economy, the bioeconomy and the collaborative economy ("sharing economy) [11].

Some opinions suggest that the circular economy can be seen as a form of green economy, which aims to replace traditional market rules with environmental rules to guide society's economic activity. In this sense, Negrei and Istudor argue that the circular economy incorporates the principles of industrial ecology, a field of applied ecology that addresses critical aspects of current economic systems such as the use of current energy-intensive technologies, linear techno-productive systems or sectoral management approaches [12].

The concepts associated with the circular economy are also different in terms of their application in practice, taking into account the particularities of the countries of the world [19]. Research conducted by Ghisellini, Cialani and Ulgiati reinforces that there are notable differences in the way the circular economy is implemented in different parts of the world, reflecting the economic, social and cultural specificities of each country or region [4].

But all of these approaches demonstrate that the circular economy is not just an economic strategy, but also a complex movement to protect the planet and secure a sustainable future that not only reduces pressure on natural resources, but also contributes to a more resilient and sustainable economic system. In this sense, the circular economy can be considered a true "catalyst for the common good".

3. CIRCULAR ECONOMY (CE) IN ROMANIA

The circular economy has gained wide acceptance within the European Union, where it is seen as a vital response to resource security issues. Romania has taken on the commitments established at EU level, in particular through the European Ecological Pact and the Action Plan for the Circular Economy, in order to contribute to the achievement of the common objectives of sustainability and environmental protection. These commitments reflect the need for a transition towards a more sustainable and responsible economic model. To this end, Romania has adopted important strategic documents setting out national guidelines for integrating the principles of the circular economy.

Romania is facing a number of challenges in implementing the circular economy, both at governmental level, where not all the necessary documents have been drawn up, and at the level of entrepreneurs and consumers, who still do not have sufficient knowledge of the situation.

A significant step towards a sustainable development is the adoption of the National Strategy for Circular Economy in 2022, which is an essential strategic framework for integrating the principles of circular economy in Romania's economic development, complemented by another legislative document to support the circular economy in Romania, the Action Plan for the Implementation of the Circular Economy

So far, the biggest circular economy project in Romania, aimed at supporting the collection and recycling targets imposed at the European level, is the Guarantee-Return System (SGR), which became operational at the end of 2023, after a long period of delays and preparations. We can say that this project marked an important step in Romania's transition towards a more sustainable economy.

In Romania, the opportunities of the circular economy are considered to be closely linked to environmental protection, increased competitiveness and the contribution of the results of technological innovation and research. Tașnadi and al. believe that the circular economy and eco-innovation contribute to increasing Romania's growth potential by responding to urgent challenges such as climate change, resource depletion and biodiversity conservation [14].

4. THE TRANSITION OF THE MINING SECTOR FROM LINEAR TO CIRCULAR MODEL. REALITY AND CHALLENGES

Romania is specific to an economic and social development context within the European Union characterized by an industrial structure with a fairly strong production component with a significant share of employment in sectors with a high level of GHG emissions.

The application of the circular economy model in the mining sector implies a holistic approach to the life cycle of products, from initial design to waste management. By using advanced technologies, recycling materials from used products and reusing mining waste, the amount of natural resources required and the impact on ecosystems can be significantly reduced. In this context mining waste, such as tailings, can be reused as construction materials or in other industries, turning an environmental problem into an economic opportunity. In addition, sustainable product design can facilitate the recovery and reuse of critical raw materials, thereby reducing the risks associated with limited resource availability.

The mining industry in Romania, and beyond, continues to face numerous challenges due to its potential impact on the environment. These challenges are becoming increasingly difficult to overcome with growing social awareness or governmental pressure, requiring a new, more creative approach to resource management and waste utilization.

The current state of the mining sector is dominated by the closure or downsizing of many mining operations. Most mining operations are either closed or in the process of closure, with the exception of a few mines still extracting coal (mainly lignite), which continues to be exploited for energy purposes, although its use is gradually decreasing in the context of the energy transition and carbon reduction commitments, or those mining salt and construction materials.

Starting from this state of affairs, it is only natural to ask the question: what does the transition of the Romanian mining sector from the classic linear model to a circular one entail?

The application of circular economy principles to resource exploitation must be realized in all stages of the life cycle of the processes from extraction and design to waste management [9], covering also the post-closure monitoring part of mining operations. [11]. This approach can redefine how resources are perceived and utilized in the economy

According to Romania's mining strategy 2018-2035 Romania is estimated to have several deposits of useful mineral substances, but with a low content of useful elements. According to the principles of the circular economy in the mining industry, it is recommended to take into account the principle of eco-efficiency, whether it is prospecting or opening new deposits or managing old waste dumps containing useful mineral substances. This principle implies maximizing the value obtained from available resources and preserving their recycling potential for as long as possible [11]. Eco-efficiency has also been identified as a key characteristic of a sustainable mining operation, where optimizing extraction and minimizing the amount of valuable waste material would help to solve problems such as lower ore grade and increase economic viability [15].

Romania faces a significant challenge related to the management of mining waste, having the highest percentage of waste from the extractive industry in Europe, more than 85% of total waste, compared to a European average of around 25%. This significant volume originates mainly from historical mining activities, which have left behind tailings dumps, tailings ponds and other forms of tailings [18]. Many types of mining waste can be generated during the life cycle of a mine [13]. A suggestive picture is shown in Fig. 1.

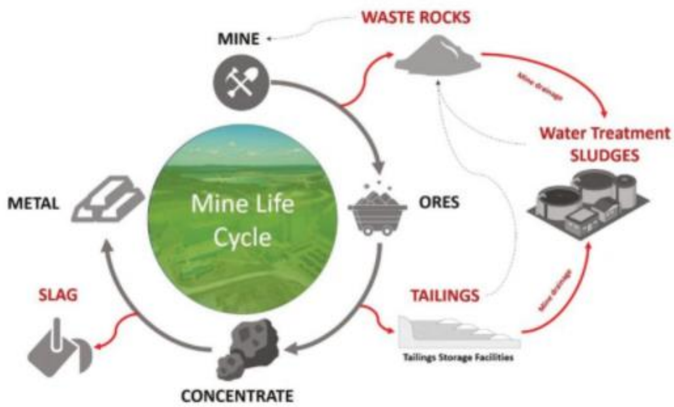

Figure 1. A mine’s life cycle and types of mine wastes
Source: Taha, Y., Benzaazoua, M. (2020), Towards a Sustanable Management of Mine Wastes, Journal of Mining

Romania is also facing a major challenge in terms of waste management, currently having the highest landfill rate in the European Union at 72%, in significant contrast to the EU average of 25.6% [18]. This situation highlights the urgent need to adopt policies and measures to bring the country in line with European standards and facilitate the transition to a circular economy.

Mining wastes, depending on their category - hazardous or non-hazardous - have a special status that determines the specific treatments they can undergo in order to minimize the environmental impact and facilitate the reuse of resources. As a result, the solutions that can be applied are specific, with little scope for transferability from one situation to another.

But it is precisely this considerable volume of mining waste and its significant environmental impact that offers great opportunities for its integration into the circular economy model. This approach can transform waste from an environmental problem into a valuable resource, thereby contributing to the sustainability of the extractive industry and protecting the environment.

The transition to the Circular Economy in the mining sector offers multiple benefits, but entails a number of critical challenges that need to be taken into account to ensure effective and sustainable implementation, such as:

- bottlenecks caused by certain legislative measures

- institutional or economic bottlenecks
- technological and environmental bottlenecks

The motto "getting more from less" is a key principle in the transition to the circular economy, especially in the mining industry, where resources are finite and the extraction process can be economically and environmentally costly [15]. But to implement this principle successfully, the mining industry must adopt strategic approaches that maximize efficiency and minimize waste and environmental impacts. Wang, Y.M. believes that by following the 3Rs (reduce, succeed, recycle) principle can make a significant contribution to promoting a sustainable business model and combating environmental problems by [20]:

- Improving overall resource extraction by maximizing waste materials and minerals;
- rehabilitating mining lands in an integrative manner and utilizing them for new mining activities;
- Turning closed mines into museums or as science education points;
- the use of tailings to backfill mines;
- improving water and material reuse through innovative technologies and cyclical systems;
- maximizing the use of waste and by-products.

3. CONCLUSIONS

On the one hand the planet's natural resources are limited and on the other hand the resource demand for raw materials is increasing [6]. To ensure the availability of resources in the future, current patterns and volumes of production and consumption need to change dramatically, necessitating a complete rethinking of the way things are done. The linear model of economic development has increasingly serious consequences leading to resource depletion, environmental pollution, poor waste management. The type of linear economic model known as "take, make, dispose", based on the classic path followed by mining operations: extracting the ore, processing minerals and metals, producing the end product and disposing of waste, will have to be replaced by innovative, environmentally responsible alternatives. And this is where the circular economy comes in, an economic model that emphasizes maximum resource efficiency and reduced pollutant emissions, with positive consequences for a sustainable future. By integrating the principles of reduce, reuse and recycle, the circular economy not only supports economic development, but also helps to protect the environment, reduce inequality and promote a more resilient and equitable economy. Thus, the circular economy can be the key to overcoming the resource and pollution crisis, while ensuring long-term prosperity for all stakeholders.

The Romanian mining sector is at a crossroads. The mining industry is facing significant waste and resource management challenges as valuable ores are increasingly depleted and the amount of waste ore is growing. Consequently, a successful transition of the mining sector towards a circular economy requires the implementation of actions addressing all stages of the value chain: extraction and transportation of raw materials, production, waste management and recycling, which offers a significant contribution to addressing emerging resource and climate issues. Furthermore, a change of mindset is needed in the management of mining companies. The transition to the circular economy requires a paradigm shift in the way mining companies define their success. Instead of success being measured solely by short-term financial profit, companies should adopt a long-term vision that emphasizes sustainability, social responsibility and environmental protection. These objectives can be integrated into business models, alongside the assessment of the environmental and social impacts of mining activities. A defining element is the development of an organizational culture that promotes sustainability. Mining companies can encourage the development of an internal culture that emphasizes innovation and the application of circular economy principles in all processes. In addition, a legal and regulatory framework that supports the move towards a circular economy through policies and instruments that support not only waste reduction and resource efficiency, but also investment in research and development (R&D) for cleaner and more sustainable technologies. These policies should also promote sustainability education and encourage collaboration between regulators and mining companies.

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RETRAINING THE JIU VALLEY MINING WORKFORCE: PERSPECTIVES FROM HUMAN RESOURCES MANAGEMENT

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Abstract: *The paper analyses the challenges and opportunities for workforce reconversion in the Jiu Valley, focusing on the decline of coal mining and the need for sustainable economic alternatives. It highlights the socio-economic crisis caused by the mine closures, including high unemployment rates (8.4% compared to the national average of 5.3%), youth migration and the dependency of 30% of the population on social assistance. Key strategies proposed include tailor-made training programmes in renewable energy, IT and ecotourism, supported by partnerships with local authorities, private companies and international institutions. Examples from Poland and Germany demonstrate the success of similar initiatives, with a focus on energy transition and digital skills development. European funding mechanisms, in particular the Just Transition Fund, are identified as essential factors for implementing these solutions. The document underlines the importance of psychological support, continuous monitoring of progress and collaborative efforts to create a resilient and inclusive local economy.*

Key words: *human resource management, workforce reconversion, strategies, renewable energy, ecotourism*

1. INTRODUCTION

The Jiu Valley, located in Hunedoara County, is a historical region of Romania known for its coal mining industry. Over the decades, mining has shaped not only the economy, but also the culture and identity of local communities. However, the gradual closure of mines, as part of the global energy transition, has led to an economic and social crisis in the region, requiring urgent measures to retrain the workforce.

The closure of mines represents not only job losses, but also a profound change in the social and economic structure of the region. This change has generated a series of complex problems, such as the migration of the young population, the drastic decrease in local incomes and a cultural resistance to change. In the absence of strategic interventions, these challenges risk perpetuating a cycle of poverty and social exclusion. From a human resource management (HRM) perspective, it is essential to address this situation through well-founded, integrated and sustainable solutions, using innovative methods and international good practices. The article presents a detailed analysis and proposes strategic directions to transform these challenges into real opportunities.

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2. CURRENT LABOR MARKET CONTEXT

In the 1980s, mining in the Jiu Valley provided jobs for over 40,000 people, being a major economic driver of the region. According to data provided by the National Institute of Statistics (INS), this industry provided about 85% of the income of local families, being a key factor in economic and social stability. Mining-related businesses, such as transportation and equipment maintenance, contributed additionally to the local economy. However, with the decrease in demand for coal in the 1990s and the adoption of environmental protection measures promoted by the European Union since 2000, the decline of the mining industry became inevitable.

Today, only four mines are still operating in a conservation regime, and the unemployment rate in the area continues to be alarming. According to INS data from 2021, the unemployment rate in the Jiu Valley is 8.4%, compared to the national average of 5.3%. This gap reflects not only an economic problem, but also the absence of alternative opportunities for the workforce. In parallel, birth data show a continuous decline since 2005, with an average annual decline of 2.1% in the number of births. These trends are doubled by the constant migration of young people to other more prosperous regions or outside the country, which amplifies depopulation and the weakening of the local economic base.

In addition, about 30% of the region's active population depends on forms of social support, according to the Ministry of Labor's 2022 report. This phenomenon not only worsens economic vulnerability, but also creates significant pressure on the local budget. At the same time, in the absence of effective retraining initiatives, many residents remain trapped in a vicious circle of poverty, without the prospect of sustainable jobs.

This situation is illustrated in the graph below, which compares the unemployment rate in the Jiu Valley with the national average:

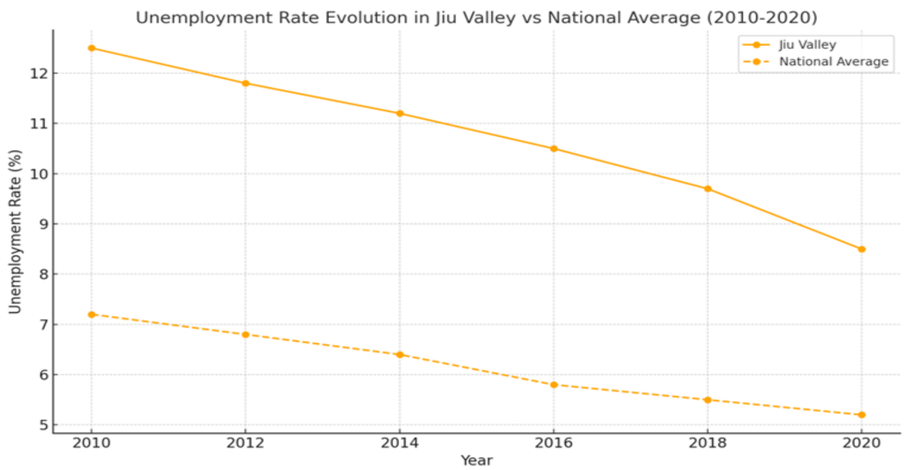

Figure 1. Comparison of the unemployment rate in the Jiu Valley versus the national average

To address these challenges, it is essential to identify the skills gaps of the active population and develop a coherent reskilling strategy. Such a strategy should include collaboration between authorities, the private sector and educational institutions to create training programs that respond to the real demands of the labor market.

For example, areas such as renewable energy, information technology and mountain tourism may offer attractive prospects. A holistic approach must also include psychological and motivational support for the affected residents, given the profound impact that job losses have on the identity and morale of local communities. Accessing financial resources available through programmes such as the European Union's Just Transition Fund is essential to finance these initiatives.[5]

3. SPECIFIC CHALLENGES FROM AN HUMAN RESOURCES MANAGEMENT PERSPECTIVE

A. *Skills not adapted to current market requirements*

Many former miners have technical skills strictly related to the extractive industry, which do not match the requirements of emerging sectors such as IT, renewable energy or services. According to a 2022 report by the Ministry of Labor, over 65% of mining workers have specialized skills that cannot be used in other fields without retraining. For example, the requirements for photovoltaic installations or maintenance in the wind energy industry involve completely different skills, such as operating specialized software and understanding modern technological flows. This lack of adaptability limits employment options and increases dependence on social assistance programs. In addition, many of these workers have not had access to continuous training in the last 10-15 years, which exacerbates the gap with current market requirements.

It is crucial that HRM strategies focus on building transferable skills, such as digital, management or communication skills. According to a study by the European Training Foundation [6], tailored training programs can increase the employability rate of former miners by up to 45% within two years. This process could include tailored retraining courses, internship programs or partnerships with employers from relevant sectors. Successful examples from Germany, where former miners were integrated into green energy industries, could serve as a model for Romania.

B. *Resistance to change*

The traditional mentality in the region slows down the reconversion process, requiring significant motivation and awareness-raising efforts. The local culture, strongly linked to mining, can create a negative perception of new areas of activity. According to a survey conducted by the National Institute of Statistics in 2020, over 70% of residents of the Jiu Valley believe that mining should be the main economic sector, despite its inevitable decline. In addition, there is a sense of uncertainty about the economic viability of new jobs, fueled by the lack of clear information about existing opportunities.

Therefore, motivational coaching programs and success stories of those who have managed to make the transition can play an essential role in changing this mentality. Public information campaigns, supported by authorities and NGOs, can contribute to reducing this resistance.

For example, in Slovakia, an information campaign focused on the benefits of renewable energy increased interest in retraining among former miners by 30% in just one year, according to a 2021 report by the European Energy Transition Network [6].

C. *Lack of personalized training programs*

General vocational training is not enough; programs tailored to the profiles and needs of local communities are needed. A 2021 European Commission report [5] highlights that personalized training programs, which take into account the specific needs of regions, can increase the success rate of professional reconversion by over 50%. Each program should be built on the basis of an audit of existing skills and specific labor market requirements. For example, in the Jiu Valley, areas such as photovoltaic panel installation, organic farming, and mountain tourism present significant potential for job creation.

In addition, these programs should include elements of mentoring and post-training support to ensure effective integration into the labor market. Digital training platforms, such as Coursera or Udemy, can be used to provide access to modern educational resources.

A successful example is the use of these platforms in Poland, where over 10,000 former miners were retrained between 2018 and 2022 to work in the IT and renewable energy sectors.

D. *Migration of skilled labor*

Young people and people with transferable skills migrate to other regions or countries, which amplifies depopulation. According to INS data from 2022, the active population of the Jiu Valley has decreased by over 15% in the last 10 years, with the majority migrating to more developed urban regions or outside the country. This trend can be combated by creating competitive local economic opportunities that motivate young people to stay in the region.

In addition to job creation, it is important to develop local infrastructure, such as access to quality education, health services and recreational activities. A study conducted by the World Bank in 2020 shows that investments in social infrastructure can reduce the intention to migrate by up to 25%. Investments in local infrastructure and support for entrepreneurial initiatives can represent long-term solutions, transforming the Jiu Valley into an attractive place for young people and families. For example, the creation of a regional technology park, similar to initiatives in the Czech Republic, could provide a significant boost to local economic development .

4. **DEVELOPMENT OPPORTUNITIES THROUGH HUMAN RESOURCES MANAGEMENT**

A. *Retraining through sectoral training programs*

Vocational retraining is a central pillar of economic revitalization in the Jiu Valley. It is essential to develop courses that directly address the needs of emerging sectors, such as renewable energy, IT and eco-tourism. According to a 2022 report by the International Energy Agency [8], the renewable energy sector will generate approximately 1.2 million jobs in Europe by 2030. In this context, the Jiu Valley can benefit from this trend by training specialists in the installation and maintenance of photovoltaic panels, wind turbines and other green energy solutions. For example, courses organized in partnership with companies such as CEZ Romania or Enel can facilitate the rapid integration of graduates into the local and regional labor market.

National statistics show that the success rate of IT retraining graduates is over 70% nationwide, according to a 2021 report by the Ministry of Labor. In addition, the field of ecotourism, with significant potential in the Jiu Valley due to its mountainous landscapes and cultural heritage, can generate sustainable jobs for local communities. A 2020 report by the World Tourism Organization highlights that regions that invest in sustainable tourism experience annual economic growth of up to 8%.

It is important that these programs are designed in collaboration with local and national employers to ensure the relevance and applicability of the skills developed. Employers can contribute by providing technological know-how, practical simulations and access to modern equipment. For example, similar partnerships in Poland and Germany have recorded an employment rate of over 85% for participants, according to a 2021 European Union report.

In addition, partnerships with international universities or institutions, such as the University of Petroșani or other technical universities in Europe, can facilitate an efficient transfer of know-how and modern educational standards. These collaborations can include student exchange programs, online courses and participation in applied research projects. A notable example is the Erasmus+ program, which provides funding for such initiatives, considerably increasing the chances of success of local programs. In the context of the Just Transition Fund, these collaborations can attract additional financial resources, which would support the expansion of these programs and ensure their long-term sustainability.

B. *Creating regional centers of excellence*

Centres of excellence can become educational and innovation hubs in areas such as green technology and digitalisation, thus supporting the economic transition. These centres could provide not only vocational training, but also support for entrepreneurship, applied research and the development of sustainable local solutions. They can serve as a catalyst for innovation, attracting investment and resources to the region. For example, in Poland, such a centre was established in 2019, generating 250 jobs in its first year of operation, according to a 2020 OECD report [9].

C. *Stimulating local entrepreneurship*

Through microfinance and dedicated grants, new businesses in tourism, organic farming and services can be created. This would allow for local job creation and contribute to economic revitalization. The development of business incubators and support networks for entrepreneurs can stimulate local initiatives and reduce the risks associated with starting a business. According to a 2022 European Commission report, regions that adopted similar strategies experienced economic growth of up to 5% within three years.

D. *Use of European Funds for reconversion*

The Just Transition Fund provides considerable resources for financing local initiatives. Examples of success from other countries [4]:

Country	Funded project	Amount (EUR million)
Germany	Digital retraining	50
Poland	Solar energy	75
Czech Republic	Light industry	40
Romania	Ecological tourism	30

These examples show how European funding can support professional retraining and economic transition. It is essential that HRMs effectively manage the access to these funds and their implementation in concrete projects. Funding programs should be complemented by clear monitoring and evaluation mechanisms to maximize the impact of investments.

5. STRATEGIC SOLUTIONS FOR HUMAN RESOURCES MANAGEMENT

A. *Regional skills audit*

Conducting an audit of the skills of the working population is a critical step to identify the areas where retraining can have the greatest impact. According to a 2022 report by the Ministry of Labor, approximately 60% of the working population in the Jiu Valley has technical skills specific to the mining industry, which limits the possibilities for professional retraining. This audit must include several fundamental steps to ensure maximum accuracy:

- Quantitative and qualitative analyses: Statistical data on education levels, existing skills and demographic distribution must be complemented by interviews and focus groups with local employers.
- Identifying skills gaps: Comparing the current skills of the population with emerging economic requirements in areas such as IT, renewable energy and eco-tourism.
- Assessing regional economic trends: Detailed studies on the potential growth of industries in transition can help prioritize investments in vocational training.

According to Eurostat (2021), similar regions in Europe reported an increase in employment of up to 25% when skills audit was used to guide retraining interventions.

Example from the Ruhr Region, Germany

The Ruhr region in Germany is a successful model for the use of skills audits. Between 2015 and 2020, a detailed skills audit enabled the retraining of over 15,000 miners, 80% of whom were employed in areas such as IT and green energy [9]. The programme included:

- Collaborations with local and international companies to identify specific skills needs.
- Creating personalized training programs, with internships included.
- Monitoring participants' progress through digital platforms, ensuring rapid curriculum adjustments.

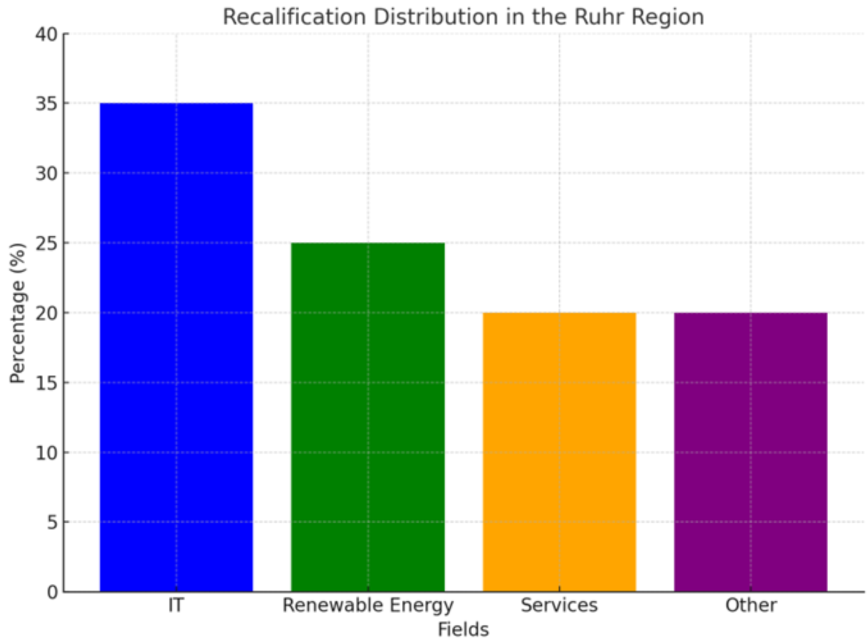

Figure 2. Distribution of retraining areas in the Ruhr Region

The graph shows the percentages of graduates scheduled to work in IT (35%), renewable energy (25%), services (20%), and other fields (20%).

Anticipated benefits for the Jiu Valley

Applying a similar model in the Jiu Valley could lead to:

- Increase the employment rate in emerging sectors by 20-30% in the next five years.
- Reducing the unemployment rate from 8% to below 5%, approaching the national average.
- Developing a more diversified and resilient local economy.

Table 1. Forecasted audit results in the Jiu Valley

Indicator	Current value	Forecasted value after audit
Unemployment rate	8%	5%
Green energy jobs	5%	25%
IT jobs	2%	15%
Average monthly income (EUR)	400	600

Conducting the audit represents the foundation on which effective professional retraining programs can be built, adapted to the current and future needs of the labor market.

B. *Collaborative training programs*

Public-private partnerships are an effective model for developing courses tailored to the needs of the labor market. Such collaborations can involve the local university, local authorities, and companies in emerging sectors. The University of Petroșani, for example, can play a central role in developing educational programs in partnership with renowned companies, such as Enel or Hidroelectrica, to train specialists in renewable energy [14].

In Poland, similar partnerships between universities and the private sector led to the development of intensive training programs that had a professional insertion rate of over 75%, according to a study conducted by the European Training Foundation in 2020. Implementing similar strategies in the Jiu Valley could support the immediate integration of graduates into the local labor market.

C. *Motivational and coaching programs*

Implementing coaching sessions is essential to help former miners rediscover their strengths and embrace change. These programs should include individualized development plans, psychological support, and access to experienced mentors. According to a 2021 World Bank report [11], personalized coaching programs can increase participants' chances of success in the professional retraining process by 30%.

A practical example is the initiatives in Slovakia, where former mining workers were included in coaching and training programmes, and the results showed an increase in motivation and improvement in transferable skills. These programmes were implemented in collaboration with international organisations such as the European Training Foundation (ETF) and the Slovak Ministry of Economy. According to a 2020 ETF report, 68% of participants were able to find jobs in emerging industries such as renewable energy and logistics within a year of completing the programme. Through coaching, participants can be helped to redefine their perspectives and set realistic goals. For example, a participant who previously worked as a mining mechanic was retrained and employed as a wind turbine maintenance technician.

Psychological support also plays a key role. According to a study conducted by the World Health Organization in 2021, job loss is associated with a 25% increase in the risk of depression. Psychological support programs included in the initiatives in Slovakia helped to reduce these effects, supporting the social and economic integration of participants. In addition, periodic assessments showed a 40% improvement in mental health indicators for participants who benefited from coaching and psychological counseling sessions.

D. *Progress monitoring*

Monitoring progress is essential to assess the success of retraining programmes and to ensure transparency in the process. Establishing key indicators, such as the post-training employment rate, the number of new businesses created and the impact on the local economy, is vital. For example, in the Silesia region of Poland, a robust monitoring system allowed retraining programmes to be adjusted in real time, increasing their efficiency by 20%, according to a report by the European Commission [4].

In Silesia, the use of a digital monitoring system allowed for the collection of detailed data on the progress of each participant, including indicators such as technical skills progress, course completion rate and job placement. According to a 2020 report by the European Training Foundation, real-time monitoring was a key factor in increasing the effectiveness of the programs, allowing for adjustments to the curriculum and teaching methods.

A concrete example is the implementation of Learning Management Systems (LMS) platforms, used to track course attendance, module completion and exam results. Also, feedback from participants was integrated into the planning of future retraining programs. The graph below illustrates the results of monitoring in the Silesia region, highlighting the increase in the post-training employment rate:

Monitoring can also contribute to increasing trust in the proposed initiatives, by regularly publishing results and organizing feedback sessions with beneficiaries. Digital platforms have allowed for reducing data processing time and improving access to information for all parties involved.

Monitoring can also contribute to increasing trust in the proposed initiatives, by regularly publishing results and organizing feedback sessions with beneficiaries. A concrete example is the use of digital platforms to track the progress of participants, which allows for the rapid identification of potential obstacles and the implementation of personalized solutions.

Table 2. Comparative Table- Successful Initiatives in Other Countries

Country	Initiative	Result obtained
Germany	Retraining programs in IT and green energy	85% employment rate in 2 years
Poland	Public-private partnerships for training	Regional economic growth of 5%
Slovakia	Coaching and psychological support for miners	Improving mental health and increasing motivation
Romania	Training in ecotourism (pilot)	30% of participants employed within 6 months

By implementing these strategic solutions, the Jiu Valley can become a successful example of workforce reconversion, contributing to a sustainable and inclusive local economy.

Funding and Implementation Methods

European funds are a crucial source for implementing professional retraining strategies. The Just Transition Fund (JTF), part of the European Green Deal, allocates approximately EUR 19.2 billion to regions affected by the energy transition. Romania can access approximately EUR 2 billion of this fund, a significant part of which is intended for the Jiu Valley region.

Table 3. Distribution of JTF Funds in Europe

Country	JTF allocation (EUR million)	Priority areas
Germany	2,250	Renewable energy, digitalization
Poland	3,500	Industrial modernization
Romania	2,000	Professional retraining, green infrastructure
Slovakia	800	Social support and retraining

The data is taken from European Commission reports (2020-2021), European Parliament Reports (2021) and OECD Policy Briefs (2020).

The implementation of the funds must be supported by collaborations between authorities, the private sector and NGOs. For example, the funds can be used for:

- Creating regional technology hubs to support the development of digital skills.
- Organizing training programs in collaboration with international universities.
- Financing startups in the field of green energy and eco-tourism.

By applying these solutions and using funds efficiently, the Jiu Valley can become a European example of success in the transition to a sustainable and innovative economy.

3. CONCLUSIONS

Approaching the reconversion of the Jiu Valley workforce from a human resources management perspective offers practical and sustainable solutions. Through close collaboration between authorities, the private sector and the community, the region can become a success story for other mining areas affected by the energy transition. HRM plays a central role in facilitating this transition, contributing to building a resilient and inclusive local economy. By efficiently using available resources and mobilizing the community, the Jiu Valley can redefine its economic and social future. This transformation requires the active involvement of all local and international actors, access to adequate financing and a firm commitment to sustainable development.

With well-planned planning, including continuous monitoring, customized programs and innovative solutions, the Jiu Valley can become a successful model for economic reconversion in Europe. In this regard, investments in education, infrastructure and technology are essential to create an environment conducive to economic development. By capitalizing on natural resources, human potential and attracting new business opportunities, the region can become a regional center of innovation and economic sustainability.

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SUSTAINABLE DEVELOPMENT – A NEW APPROACH FOR A NEW REALITY

Mirela ILOIU[1], Sorin Radu ILOIU[2]

Abstract: *This paper explores the concept of sustainable development and highlights the significance of adopting a systematic approach to sustainable development strategies at the national level. In Romania, the implementation of the 2030 Agenda for Sustainable Development and its adaptation to the country's specific context are facilitated through the revision of the National Strategy for Sustainable Development. Moreover, the pandemic has underscored the need to reassess and refine this concept, prompting a rethinking of business strategies moving forward.*

Key words: *sustainable development, strategy, environment, resources, business strategy, pandemic*

1. INTRODUCTION

The notion of sustainable development gained significant global traction during the 1992 Earth Summit held in Rio de Janeiro. This groundbreaking conference addressed vital issues such as biodiversity preservation and the reduction of greenhouse gas emissions, advocating for a delicate equilibrium between economic progress and environmental safeguarding.

Nonetheless, skepticism arose from numerous nations in the Global South. These countries expressed apprehensions that stringent environmental policies might hinder their economic advancement. Their concerns stemmed from historical inequities: while industrialized nations had historically achieved economic growth often at the expense of environmental health, developing countries were striving for similar opportunities without equivalent resources or leeway.

To bridge these divergent perspectives, the principle of sustainable development was integrated into the key agreements and treaties that emerged from the Earth Summit. This paradigm sought to align economic ambitions with environmental responsibility, asserting that development must cater to present-day needs without jeopardizing the ability of future generations to meet theirs. By embracing this dual commitment, sustainable development offered a pathway for reconciling economic and ecological priorities, fostering collaborative efforts to address global sustainability challenges.

2. CONCEPT OF SUSTAINABLE DEVELOPMENT

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The concept of sustainable development was initially articulated by the Brundtland Commission in its report *Our Common Future*, defining it as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [2], [6].

What sets sustainable development apart from traditional environmental policies is its commitment to resource conservation for future generations. The primary goal of sustainable development (SD) is to achieve long-term stability for both the economy and the environment. This is accomplished by integrating economic, environmental, and social considerations into decision-making processes.

Sustainability is underpinned by several fundamental principles: [3]

- *Intergenerational Equity***:** This principle emphasizes the need for a forward-looking approach, ensuring that the needs of future generations are addressed through sustainable actions.
- *Polluter Pays Principle***:** According to this principle, those who cause environmental harm are responsible for bearing the costs of their actions, rather than transferring these costs onto society or nature.
- *Precautionary Principle***:** This principle asserts that scientific uncertainty should not delay the implementation of cost-effective measures aimed at preventing environmental degradation. It is particularly pertinent when facing the risk of severe or irreversible damage [8]. Additionally, this principle recognizes the unequal contributions of developed and developing nations to environmental harm, placing greater responsibility on developed nations due to their historically higher resource consumption and environmental impacts.
- *Integrated Decision-Making***:** The cornerstone of sustainable development is the incorporation of environmental, social, and economic dimensions into every level of policy and decision-making.

The integration of these aspects as a core value is what fundamentally differentiates sustainability from other policy frameworks [2], [6].

3. SUSTAINABLE DEVELOPMENT STRATEGY

The OECD Development Assistance Committee (DAC) [4] defines a sustainable development strategy as a coordinated framework of participatory and evolving processes that integrate economic, social, and environmental objectives. These strategies aim to reconcile competing priorities by implementing necessary trade-offs (figure 1).

Findings from dialogues conducted in various countries for OECD DAC policy guidance emphasize that implementing a sustainable development strategy often requires enhancing and coordinating existing strategic planning frameworks. Key areas for improvement include:

- Ensuring policy coherence across different sectors.
- Enhancing the effectiveness of implementation measures.
- Increasing political focus on strategic planning.
- Strengthening leadership and understanding of these frameworks.

While sustainable development strategies may appear linear, their practical application necessitates a cyclical improvement model. This involves continuous monitoring, evaluation, and renewed discussions on critical issues to ensure adaptability and relevance.

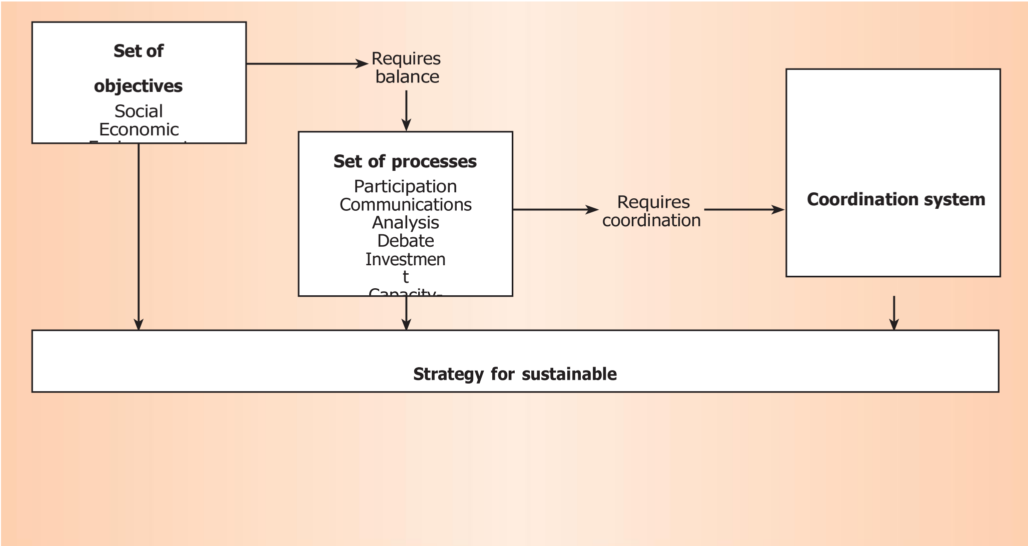

Figure 1: Framework for Systematic Sustainable Development Strategies

(Note: Although Figure 1 may suggest a linear sequence for implementing sustainable development strategies, in practice, these strategies demand a cyclical and iterative process. Continuous monitoring and evaluation of both processes and outcomes enable dynamic debates on emerging priorities and challenges.)

As part of the OECD DAC project on strategies for sustainable development, dialogues with stakeholders were held in participating countries to review current and past planning processes. These dialogues sought to examine methodologies, identify successes and failures, and uncover underlying factors influencing outcomes. Insights from these discussions led to the identification of crucial steps to enhance planning processes and align them with sustainable development goals. This process involves ongoing identification, coordination, and improvement of mechanisms to balance economic, social, and environmental priorities across diverse stakeholders.

Figure 2: Mechanisms Supporting Sustainable Development Strategies

Figure 2 illustrates the essential mechanisms required for designing and implementing sustainable development strategies. At the core is the facilitation of societal consensus on shared visions, goals, and objectives for sustainability. Supporting this core are institutional and informational mechanisms that work cohesively to drive implementation efforts [1].

The increasing recognition of strategic approaches highlights the lessons learned from past inefficiencies in achieving sustainable development goals. Countries are now leveraging the concept of sustainable development as an opportunity to redefine nation-building initiatives. Consequently, strategy documents often emphasize the need to enhance national capacities for strategic policymaking and planning.

4. SUSTAINABLE DEVELOPMENT STRATEGY IN ROMANIA

Romania boasts a rich history as a sustainable and resilient society, characterized by one of Europe's oldest rural civilizations. This heritage reflects a deep connection with nature and a wealth of traditional knowledge about sustainable living. Nicolae Georgescu-Roegen's revolutionary 1971 publication, *The Entropy Law and the Economic Process*, marked a milestone in conceptualizing sustainable development. For Romania, as for all nations, sustainable development is not merely an alternative; it represents the only rational path forward.

The implementation of the 2030 Agenda for Sustainable Development in Romania, along with its 17 Sustainable Development Goals (SDGs), has been tailored to national characteristics through revisions to the National Strategy for Sustainable

Development. This revised strategy is based on the premise that sustainable development fosters a mindset that, once embraced by citizens, contributes to the creation of a more equitable, solidarity-driven society capable of addressing global, regional, and national challenges.

The strategy's three pillars—economic, social, and environmental—address these challenges comprehensively:

- **Economic Pillar:** Long-term, inclusive economic growth is essential for improving the well-being of all Romanian citizens. Transforming the economy into a sustainable model requires innovation, resilience, and optimism. A focus on fostering entrepreneurial culture and leveraging free market dynamics can enable individuals to reach their full potential.
- **Social Pillar:** A cohesive society must ensure access to enhanced educational and healthcare systems, reduce gender and regional disparities, and promote social inclusivity. By strengthening societal resilience and fostering institutional fairness, Romania can support citizens in fulfilling their aspirations. Public policies targeting education and health can further unlock human potential, leading to a higher standard of living for all.[5]
- **Environmental Pillar:** Awareness of environmental preservation has grown significantly in recent years. Sustainable development necessitates cultivating a sense of community and belonging that fosters social inclusion while encouraging loyalty to and stewardship of nature.

5. SUSTAINABLE DEVELOPMENT AND INVESTMENT IN ROMANIA IN PANDEMIC CONTEXT

In recent years, sustainability has emerged as a core priority for businesses operating in Romania. Companies have continuously refined their understanding of this concept, and the COVID-19 pandemic has accelerated significant trends in this regard. Notably, consumer behavior has shifted to place greater emphasis on corporate environmental and social responsibility, amplifying awareness of the environmental impact of business practices.

According to the 2020 EY study, *Sustainability and Responsible Investments in the Context of COVID-19*, 74% of surveyed businesses reported prioritizing the integration of sustainability principles into their strategies. This shift is mirrored by global trends and is driven by changes in consumer purchasing habits, growing investor demands, and increasingly stringent regulatory requirements.

The pandemic underscored the necessity for Romanian companies to reevaluate their operational and investment decision-making frameworks. There is a clear need to incorporate sustainability principles across key business functions, including supply chains, operations, research, development, and communications. Furthermore, COVID-19 highlighted the importance of long-term planning and value creation, shifting corporate focus from traditional financial metrics to qualitative performance indicators [9].

The EY study also revealed that the health and well-being of employees and business partners emerged as top priorities for most organizations during the pandemic.

Romanian companies demonstrated a willingness to invest in energy efficiency, environmentally friendly technologies, and responsible procurement practices.

Notably, 80% of professionals surveyed agreed that embedding sustainability considerations into decision-making processes positively impacts long-term operational performance. As highlighted by the study, sustainable practices are essential for fostering steady and healthy economic growth over the long term.

Some companies in Romania have positioned sustainability at the heart of their corporate strategies. These businesses not only recognize the significant financial opportunities generated by sustainable practices but also understand the importance of aligning organizational values with those of their employees. This alignment has led to increased pressure on other organizations to adopt similar measures, fostering widespread adoption of sustainability audits and certifications. These certifications reassure ecosystem stakeholders, including investors, of a company's commitment to sustainability while encouraging other entities to follow suit.

As emphasized by EY representatives, "Organizations that fail to acknowledge the long-term role of sustainability risk losing societal and market support. For instance, neglecting investor expectations regarding environmental, social, and governance (ESG) factors can lead to increased costs and, eventually, restricted access to capital markets."

Increased regulatory scrutiny regarding environmental protection, worker safety, and community welfare has further popularized the concept of sustainability among Romanian businesses. Clients are increasingly interested in evaluating their companies' contributions to GDP, state budgets, and broader social and economic impacts. Mechanisms are also being developed to translate sustainability actions into financial metrics.

Globally, many large corporations have appointed Chief Sustainability Officers (CSOs) to oversee sustainability initiatives. These executives play a pivotal role in maintaining transparent communication with shareholders and other stakeholders, ensuring alignment between strategic changes and principles of responsible capitalism. Additionally, CSOs are instrumental in demonstrating how improved non-financial performance metrics can enhance long-term financial success.

6. CONCLUSIONS

The extent to which sustainability will influence Romania's post-pandemic economic recovery and the specific principles prioritized by companies in their future investments remains uncertain. Nonetheless, sustainability is steadily becoming a cornerstone of corporate strategies. The COVID-19 pandemic has acted as a significant catalyst, presenting Romanian businesses with a unique opportunity to address modern challenges while adopting strategic approaches that promote sustainable development and create shared value for all stakeholders.

In this context, it is imperative for all companies operating in Romania, whether local entities or multinational corporations, to embed sustainability into their strategies and operations. While sustainability might not directly fuel short-term economic recovery, its role in ensuring long-term resilience and sustained growth is undeniable. Companies need to innovate, transition away from conventional "business as usual" approaches, and prioritize the development of environmentally friendly products, services, and low-carbon infrastructure.

Moreover, organizations must focus on understanding and responding to the evolving needs of their customers. The pandemic has significantly reshaped consumer behaviour, fostering heightened awareness of corporate accountability. Aligning business operations with sustainability principles will not only enable companies to meet these shifting expectations but also position them as leaders in a rapidly changing economic landscape.

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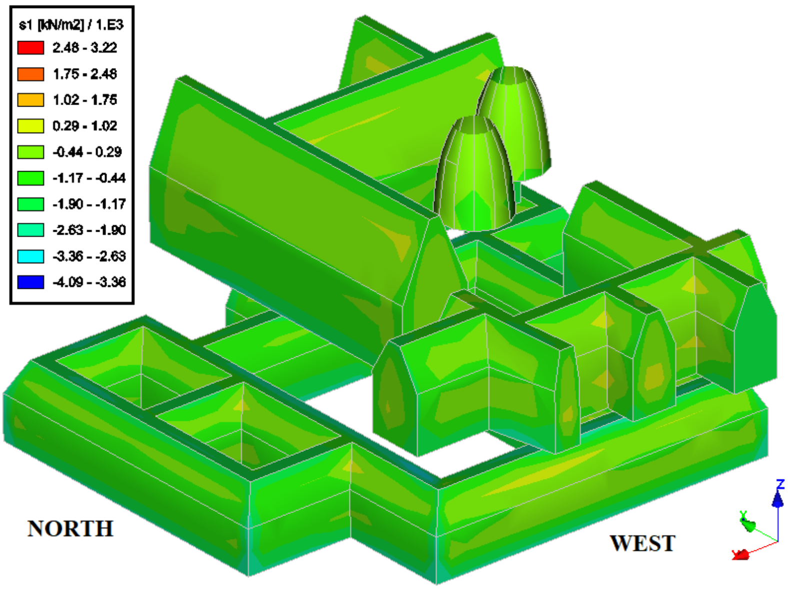

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