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DOCTORAL THESIS

- ABSTRACT -

RESEARCH ON EXPLOSION RISK ASSESSMENT IN ENVIRONMENTS WITH EXPLOSIVE ATMOSPHERES GENERATED BY FLAMMABLE GASES, VAPORS, MISTS AND DUSTS WITH AIR

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CONTENT

IMPORTANCE AND NECESSITY OF THE TOPIC. THESIS OBJECTIVES AND STRUCTURE

Over time, due to the continuous development from a technical and economic point of view, new types of materials and technological processes have emerged, that increasingly use chemical substances and compounds in liquid, gaseous or dust form, which present a high degree of flammability and combustibility, and which can lead to explosive atmospheres.

Explosions can occur in most production activities in which flammable and / or combustible substances are present, substances which may be present in the form of raw materials, intermediate products, finished products or even in the form of waste resulting from the usual production processes. Practically, at this moment, the majority of industries are affected by the probability of occurrence and initiation of potentially explosive atmospheres, because flammable and / or combustible substances are widely present in technological processes and operations.

The hazard of explosion is mainly related to the materials and substances processed, used or released by the equipment, protection systems and components involved in the production processes, as well as to the materials used in the equipment, protection systems and components construction.

Because, in most cases, after explosions significant human losses and property damage can result, the explosions risk assessment and the establishment of measures to reduce it to acceptable levels, in accordance with the rules and standards in force, is of high importance in ensuring the safety and health of people as well as material goods. Therefore, the main purpose of the risk assessment for a technical installation used in potentially explosive atmospheres is to identify the risk factors, quantify the risk level and establish the technical and / or organizational measures to be taken depending on the outcome of the assessment in order to prevent explosions and, where appropriate, to limit their effects.

In my doctoral thesis I addressed the issue of assessing the risk of explosion in environments with potentially explosive atmospheres generated by gases, vapours, mists and flammable dusts in air, with focus on assessing the risk of explosion in environments with potentially explosive atmospheres generated by combustible dusts in air. The issue addressed is current due to the increase, in recent years, of the evaluation requests due to the new types of materials, which have appeared in the pharmaceutical industry, automotive, petrochemical industry, wood processing industry, food industry, etc.

Also, the manufacturing processes of building materials, detergents, medicines, food, tobacco, furniture, plastics, as well as the processes of storage and processing of cereals involve the presence of flammable substances and combustible dusts that can form explosive dust / air mixtures.

Thus, in the doctoral thesis I presented the results of studies and research conducted to assess the risk of explosions, starting from the international technical-scientific knowledge in the field, taking into account the requirements of European norms and standards, focusing on the development of test methods for equipment housings in order to assess compliance with ATEx requirements for use in combustible dust atmospheres and laboratory tests to determine the minimum ignition energy of explosive dust / air mixtures. I also put a special accent on performing the analysis of fire and explosion hazard for bucket elevators, on which occasion I developed a model for assessing and reporting the risk of ignition for the components of a bucket elevator.

The doctoral thesis is divided into 5 chapters, to which an introductive part is added, a chapter containing the final conclusions, a summary of personal contributions and references.

The first chapter is entitled ***Fundamental concepts for explosion prevention and protection in environments with potentially explosive atmospheres generated by flammable gases, vapours, mists and dusts*** and is a synthesis of the fundamental concept of explosion prevention and protection for technical, electrical and non-electrical equipment, as well as the regulations in force regarding electrical and non-electrical equipment that are intended for use in environments with potentially explosive atmospheres.

The second chapter entitled ***Requirements for explosion prevention and explosion protection of explosive atmospheres generated by combustible dusts*** presents the principles of explosion prevention and explosion protection, as well as the requirements for the design and construction of technical equipment, protective systems and components in order to avoid ignition sources, Ex types of protection found in technical equipment, as well as the criteria for choosing the equipment and protective systems intended for use in environments with potentially explosive atmospheres generated by the air / dust mixture. Also, in this chapter are exposed some aspects related to the Ex hazardous areas classification generated by dusts, fibres or combustible lint.

Chapter three entitled A***spects regarding explosion risk assessment, operational explosion assessment tools and their validation*** deals with issues related to the general principles of explosion risk assessment and conformity assessment of products with the essential health and safety requirements of the ATEx Directive 2014 / 34 / EU in order to place them on the market. Personal contributions regarding the development of methods for testing equipment enclosures to assess compliance with ATEx requirements for use in combustible dust atmospheres are also presented.

Next chapter ***Case study on explosion risk assessment of a bucket elevator to comply with ATEx requirements for placing on the market. Personal contributions regarding the assessment procedure*** presents the classification and description of the most common bucket elevators in practice, as well as an analysis of the danger of fire and explosion in their case. This chapter includes personal contributions to the ignition risk assessment and reporting procedure for bucket elevator components.

Chapter five is entitled ***Aspects related to the process of assessing the risk of initiation of air / dust atmospheres by electrostatic discharges*** and brings in front some notions on how electrostatic charges are formed and discharged, as well as the main protection measures that can be adopted and implemented to avoid the explosions of combustible air / dust initiated by static electricity. Personal contributions are also presented both in terms of assessing the risk of ignition of the atmosphere of fuel dust / air in silos due to electrostatic discharges, and in the development of laboratory tests to determine the minimum ignition energy of explosive dust / air mixtures.

The consistent and valuable part of personal contributions is represented by:

- *Development of the ignition risk assessment method for bucket elevators;*
- *Development of tests for the verification of protection against the ingress of dust and water into enclosures and / or equipment intended for use in environments with potentially explosive dust / air atmospheres;*
- *Development of laboratory tests for the determination of explosive properties for explosive dust / air mixtures;*
- *Development of methods for assessing the risk of explosions due to the ignition of explosive dust atmospheres by electrostatic discharges.*

By applying in practice the results obtained, I have made an important contribution to the development of the necessary methods for the assessment of ignition risks in the case of bucket elevators, in order to ensure a high level of work safety in areas with combustible dust atmospheres; of the assessment methods regarding the risk of explosion due to the initiation of explosive dust atmospheres by electrostatic discharges, as well as the development of laboratory tests to verify the normal degree of protection for equipment to be used in explosive atmospheres and laboratory tests to determine explosive characteristics of explosive dust / air mixtures.

Theoretical and practical studies, analysis of technical and safety requirements, experimenting testing methods, laboratory tests and testing methods to assess the ignition hazard for technical equipment, led to improved performance of the current system of testing and carrying out the necessary assessment for the certification of equipment and materials conformity with the requirements of the European Directives.

Development of the testing methods by developing testing and assessment methodologies, conceiving and designing the testing stands, their experimentation, and validation of the testing methods, contribute to the development of the present testing/certification system's effectiveness of the Laboratory of Ex Nonelectric Equipment, Electrostatics, Materials and PPE within INCD-INSEMEX.

Development of new testing methods and procedures, following international principles and practices, provides accurate assessment of technical equipment's characteristics, equipment intended to be used in potentially explosive atmospheres. Thus, these are aligned to the European practice in the field, as well as to the improvement of the testing laboratory according to principles and requirements of SR EN ISO/IEC 17025:2018 standard, to provide necessary data for the conformity assessment with the essential safety and health requirements stipulated in the applicable European Standards.

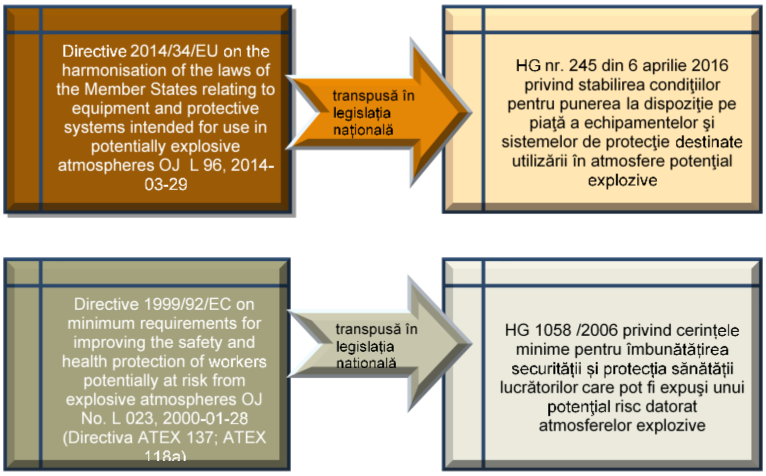
Development and creation of testing methods/procedures, by providing the necessary facilities/infrastructure, offers the possibility of knowing all the essential aspects related to the safety of the technical equipment, considering the generally ascending trend of increasing health and safety level of the workers in industries with explosion hazard.

CHAPTER 1
FUNDAMENTAL CONCEPTS FOR EXPLOSION PREVENTION AND PROTECTION IN ENVIRONMENTS WITH POTENTIALLY EXPLOSIVE ATMOSPHERES GENERATED BY FLAMMABLE GASES, VAPOURS, MISTS AND DUSTS

In the first part of this chapter, I presented some *aspects regarding the national and European legislation on electrical and non-electrical equipment intended for use in potentially explosive atmospheres*.

With the accession to the European Union, Romania, as a European country, has adopted in national legislation the majority of European Directives, including those related to ensuring health and safety at work, as well as ensuring compliance of products intended to operate in potentially explosive atmospheres.

In this, at the level of national legislation, two European Directives known as ATEx Directives have been taken over, which aim to regulate the introduction on the European market of technical equipment to be used in potentially explosive atmospheres, respectively their use in safe conditions, as follows:



Correspondence between the European ATEx Directives and national legislation

The main purpose of Directive 2014/34 / EU is to ensure a single market for technical equipment intended for use in potentially explosive atmospheres throughout the European Community, which is achieved by harmonizing the legislation of the EU component states, in which case there are sufficient tools and information, harmonized specific standards and regulations, available to stakeholders (manufacturers, certification bodies and market surveillance bodies).

With regard to Directive 1999/92 / EC, its application requires new knowledge, not covered by the rules, related in particular to the risk of explosions in case of explosive atmospheres generated by flammable dusts in the air, limiting the effects of explosions, requirements for protection against static electricity.

Next, I presented *the principles of explosion, the properties and characteristics of flammable substances that can generate an explosive atmosphere, the determination of the extent of an explosive atmosphere and the possibility of its occurrence as well as efficient ignition sources*.

An explosion is only possible if there is a source of ignition and if the concentration of the flammable substance is in the explosive range of that substance, which is given by the lower and upper explosive limits.

The mechanism underlying the explosions of mixtures of gases, vapour, mists with air can be represented graphically by the explosion triangle, from which it is observed that an explosion occurs if a flammable substance is present in the mixture with air (with sufficient oxygen) within explosion, in conjunction with the presence of an effective ignition source.

Ignition triangle

In the case of dust / air mixtures explosions, the explosion pentagon can be defined by adding to the explosion triangle aspects referring to the formation of the mixture or dispersion of combustible substances and oxidizer, as well as aspects regarding the closure of the mixture.

Pentagon of combustible dust ignition

As it is not the flammable substance itself that represents the potential danger of an explosion, but the contact, i.e., the mixture in a certain proportion of it with the air, it is necessary to know the properties and characteristics of the resulting mixture. Relevant data showing *combustion properties* are:

- flash point - characteristic of liquid substances;
- the range of explosivity - given by the explosion limits (LEL, UEL);
- limiting oxygen concentration (LOC);

In order to be able to determine the ignition properties of a potentially explosive atmosphere, it is necessary to know the following elements, which represent *the ignition requirements*:

- the minimum initiation energy of a potentially explosive atmosphere;
- the lowest ignition temperature of a potentially explosive atmosphere.

In case of air / dust mixtures, depending on the way the dust is found (deposited in the layer or present in the form of a cloud), the minimum ignition temperature is defined in two ways, as follows:

- the minimum ignition temperature of a dust cloud;
- the minimum ignition temperature of a layer of dust;

The way in which an explosive atmosphere behaves after ignition (*explosion behaviour*) is characterized by several parameters, among which there can be mentioned:

- maximum explosion pressure (p_{max});
- the maximum increase speed of the explosion pressure (dp/dt_{max});
- the maximum experimental security gap (MESG).

The formation of a potentially explosive atmosphere depends on the following aspects:

- ✓ the existence of a flammable substance in the form of gas, liquid or combustible dust;
- ✓ degree of dispersion of the flammable substance;
- ✓ the concentration of the flammable substance mixed with the air, within the explosive limits;
- ✓ the amount of explosive atmosphere sufficient to cause human loss and / or material damage following its initiation.

In order to avoid a potentially explosive atmosphere being initiated by a source of ignition, it is necessary to know what types of ignition sources may occur and what technical equipment may generate these sources. An assessment of the importance of all potential ignition sources that may come into contact with the explosive atmosphere is required. The ignition source related to the equipment is any possible source of ignition that is produced by the equipment in question, regardless of its ability to ignite.

The potential source of ignition is the ignition source related to the equipment that has the ability to ignite an explosive atmosphere (so to become efficient). The probability of becoming efficient determines the category of the equipment (they can appear in normal operation, in probable malfunction, in rare malfunction).

The efficient source of ignition is the potential source of ignition that is capable of igniting the explosive atmosphere if taken into account when it occurs (i.e., in normal operation, in probable malfunction or in rare malfunction) which determines the intended category of equipment.

If the probability of an efficient ignition source cannot be estimated, it is assumed that the efficient ignition source is present at all times.

A potentially explosive atmosphere may be initiated by at least one of the following possible sources of ignition:

- ✓ hot surface;
- ✓ flames, gases or hot particles;
- ✓ sparks that may occur due to mechanical processes;
- ✓ electrical equipment;
- ✓ stray electric currents;
- ✓ static electricity;
- ✓ atmospheric electric discharges (lightning);
- ✓ radio frequency (RF) electromagnetic waves from 10^4 Hz to $3x10^{11}$ Hz;
- ✓ radio frequency (RF) electromagnetic waves from 3×10^{11} Hz to 3×10^{15} Hz;
- ✓ ionizing radiation;
- ✓ ultrasound;
- ✓ adiabatic compression and shock waves;
- ✓ exothermic reactions.

CHAPTER 2

REQUIREMENTS FOR EXPLOSION PREVENTION AND EXPLOSION PROTECTION OF EXPLOSIVE ATMOSPHERES GENERATED BY COMBUSTIBLE DUSTS

In this chapter I presented the principles of explosion prevention and protection, some aspects regarding the classification of Ex-hazardous areas due to combustible dusts, fibres or lint and I made an analysis of the technical conditions and requirements for technical equipment to be used in areas with danger of dust explosion.

The basic principles for explosion prevention and protection derive from the need for the coincidence of the explosive atmosphere and the effective source of initiation, as well as from the analysis of the expected effects of an explosion.

Explosion prevention is a concept that can be materialized either by avoiding the occurrence of explosive atmospheres - an objective that can be achieved by changing the concentration of flammable substance, that when mixed with air generates the explosive atmosphere to a value not within the explosion range or by changing the value of the oxygen concentration to a value lower than the limiting oxygen concentration - either by avoiding all possible efficient sources of ignition.

Explosion protection can be achieved by establishing and implementing protection measures to reduce the effects of the explosion. In this case, unlike the measures that can be applied to the concept of prevention, it is acceptable to produce an explosion.

In general, the requirement to prevent explosions can be expressed in the following form: the probability that ignition sources will be present at the same time as a potentially explosive atmosphere is as low as possible. From this requirement derives the need to establish specific requirements that apply to technical equipment and protective systems depending on the specified field of use.

For the correct selection of technical equipment intended to be safely used in a hazardous environment the classification of hazardous areas is required, respectively the Ex zoning of workplaces in industrial facilities where combustible dusts are present, depending on the probability and duration of mixture formation dust / air explosives and deposition of combustible dusts in the layer.

In spaces where technological processes take place that involve the presence of combustible dusts, dust can be present in two forms: suspended dust and layered dust. Dusts form explosive atmospheres only if their concentration is within the explosive range. If a cloud with a very high concentration is present, it may not be explosive, but there is a danger that, if its concentration decreases, it will enter the area of explosiveness. On the other hand, depending on the existing conditions, not all sources of release will give rise to an explosive atmosphere of dust.

Layers, deposits and accumulations of dust must be considered as any other source of release that may form an explosive atmosphere of dust.

Ex classified areas, in case of explosive dust atmospheres are divided into zones. These areas are classified according to the frequency and duration of the explosive atmosphere of dust, as follows:

- **Zone 20:** A place where an explosive atmosphere of dust in the form of a cloud of dust in the air is present continuously or for long periods of time or frequently.
- **Zone 21:** A place where an explosive atmosphere of dust in the form of a cloud of dust in the air is likely to occasionally occur during normal operation.
- **Zone 22:** A place where an explosive atmosphere of dust in the form of a cloud of dust in the air is not likely to occur during normal operation, but which, if it occurs, will persist only for a short time.

If it has been found that a component of a technical equipment can release combustible material into the environment, it is necessary to determine, first of all, the degree of release, noting the probable duration of the release and its frequency. By going through this procedure, each source of release can be assigned a certain degree, as follows:

- ✓ continuous degree release - represents a release that occurs permanently or that occurs for long periods of time;
- ✓ release of primary grade - in this case, the release occurs periodically or occasionally, under the conditions of a normal operation of the technical equipment;
- ✓ secondary release - is the release which, under normal operation, is not expected to occur, and which, if it does occur, is likely to occur only rarely and for a short period of time.

Depending on the degree of the emission source, the probability of the occurrence of potentially explosive dust / air mixtures, as well as on the potentially hazardous dust layers, the classified areas may be designated in accordance with the following table:

Classification of areas according to the probability of the formation of potentially explosive dust / air mixtures and potentially hazardous dust layers

Source degree	**Clouds of dust**	**Layers of dust of controlled thickness**	
		Frequently disturbed	Rarely disturbed
Permanently	20	21	22
Primary	21	21	22
Secondary	22	21	22

Once the hazardous areas have been classified, a risk assessment can be made to determine whether the effects of ignition of an explosive atmosphere require a higher equipment protection level (EPL), or, on the contrary, technical equipment with a lower level of protection.

The European ATEx Directive 2014/34 / EU divides technical equipment intended for use in potentially explosive atmospheres into groups and categories, depending on their destination and the provided level of safety, as follows:

- Group I - includes equipment intended for use in underground atmospheres of mining operations endangered by the presence of firedamp, as well as in installations on the surface of these mines where there is a possibility of firedamp. The equipment belonging to this group is divided into equipment of category M1 and M2.
- Group II - includes equipment intended for use in areas where explosive atmospheres can be generated, other than those in group I. Equipment belonging to this group are divided into category 1, 2 and 3.

The new European regulations in the field of ATEx, respectively the specific standards, differentiated the gas equipment from the dust ones, the latter being included in Group III, with subgroups IIIA, IIIB, IIIC. A new term has also been introduced, that of equipment protection level (EPL): Da, Db, Dc for equipment used in potentially explosive atmospheres produced by the mixture of combustible dusts with air, respectively Ga, Gb, Gc for equipment to be used in potentially explosive atmospheres generated by flammable gases, vapour and mists mixed with air.

Correspondence between the ATEx Directive and the specific standards for group II and group III of equipment

ATEx Directive		**The new standards (SR EN ISO 60079, 80079)**	
Group II	Equipment category	Group	Equipment protection level EPL
Gases and dusts	1G	Group II Gases	Ga
	2G		Gb
	3G		Gc
	1D	Group III Dusts and fibres	Da
	2D		Db
	3D		Dc

Subdivisions of group III of equipment

Group	**Subgroup**	**Dangerous substance**
III	IIIA	Fibers
	IIIB	Non-conductive dust
	IIIC	Conductive dust

Next, in subchapter 2.3.3, I presented in detail the requirements and criteria regarding the design and construction of technical equipment and protective systems intended for use in combustible dust environments, in order to avoid the generation of ignition sources. I considered, as sources of ignition, mechanical sparks, electrical equipment and static electricity, also indicating protective measures that can be applied to prevent them from becoming effective sources of ignition.

In subchapter 2.4, I have presented, in tabular form and in detail, the types of explosion protection that are found in technical equipment, electrical and non-electrical, that are used in environments with hazard of combustible dusts. The type of protection of equipment is defined as those specific measures that apply to it, with the clear aim of preventing the initiation of an ambient explosive atmosphere.

Types of explosion protection for electrical equipment in areas with combustible dust

Protection principles	**Types of protection / reference standard**	**Category 1** **EPL Da** Very high level of protection	**Category 2** **EPL Db** High level of protection	**Category 3** **EPL Dc** Normal level of protection
Protection principle ensures that an ignition source cannot arise	Optical radiation interlocked with optical breakage SR EN 60079-28	-	Ex op sh	-
Protection principle prevents an ignition source becoming effective	Intrinsic safety Ex i SR EN 60079-11 SR EN 60079-25 for systems	Ex ia	Ex ib	Ex ic
	Inherently safe optical radiation SR EN 60079-28	Ex op is	-	-
Protection principle prevents the potentially explosive atmosphere reaching the ignition source	Encapsulation Ex m SR EN 60079-18	Ex ma	Ex mb	Ex mc Ex n*
	Pressurised enclosure Ex p SR EN 60079-2	-	Ex pxb, Ex pyb	Ex pzc
	Protection by enclosure Ex t SR EN 60079-31	Ex ta	Ex tb	Ex tc
	Protection optical radiation SR EN 60079-28	-	Ex op pr	-

Application in hazardous area

Zone 20 Zone 21 Zone 22	Zone 21 Zone 22	Zone 22

Types of explosion protection for non-electrical equipment in areas with combustible dust

Protection principles	**Types of protection / reference standard**	**Categories 1** **EPL Da** Very high level of protection	**Categorie 2** **EPL Db** High level of protection	**Categorie 3** **EPL Dc** Normal level of protection
Protection principle ensures that an ignition source cannot arise	Constructional safety SR EN ISO 80079-37	Ex h	Ex h	Ex h
Protection principle prevents an ignition source becoming effective	Control of ignition source SR EN ISO 80079-37	Ex h	Ex h	Ex h
Protection principle prevents the potentially explosive atmosphere reaching the ignition source	Liquid immersion SR EN ISO 80079-37	Ex h	Ex h	Ex h
	Pressurised enclosure Ex p SR EN 60079-2	-	Ex pxb, Ex pyb	Ex pzc
	Protection by enclosures Ex t SR EN 60079-31	Ex ta	Ex tb	Ex tc

Application in hazardous area

Zone 20 Zone 21 Zone 22	Zone 21 Zone 22	Zone 22

CHAPTER 3
ASPECTS ON EXPLOSION RISK ASSESSMENT, OPERATIONAL INSTRUMENTS FOR EXPLOSION RISK ASSESSMENT AND THEIR VALIDATION

Starting from the theoretical aspects and normative requirements presented in the previous chapters, in the first part of this chapter we made an analysis of the explosion hazard generated by hazardous materials and substances in the form of dust involved in the production process, used or released by technical equipment, protection systems and components, as well as the materials used to make the equipment, protection systems and components and we presented the main aspects to be taken into account when assessing the compliance of equipment with explosion prevention requirements. In the second part *I presented the personal contributions to the assessment of the risk of* *explosion for the marketing of products for potentially explosive atmospheres - the development of enclosure testing methods to assess compliance with ATEx requirements for use in combustible dust atmospheres.*

The risk of explosion can be defined as the probability of an explosive atmosphere occurring at the same time as the occurrence of a potentially effective source of ignition and, implicitly, the effects induced by this probability.

The current legislation, in the field of ATEx, regulates the obligations and responsibilities of persons who are engaged in the design, manufacture and use of equipment and technical installations in potentially explosive atmospheres that are produced by combustible dusts and powders, in terms of compliance with the requirements for prevention and explosion protection. According to the two European ATEx Directives, the responsibility for risk assessment and the taking of appropriate protection measures to ensure an acceptable level of safety is the responsibility of the manufacturers of technical equipment and those who use such equipment.

Thus, Directive 2014/34 / EU, transposed into Romanian legislation by GD 245/2016 regulates the obligations of manufacturers of products intended for use in potentially explosive atmospheres. In contrast, the installation of electrical and non-electrical equipment falls under the responsibility of the user who, in accordance with art. 2.4 of Annex II of Directive 1999/92 / EC transposed into our legislation by GD 1058/2006, must carry out an explosion risk assessment which will include all parts of the installation, including those not included in the scope of Directive 2014 / 34 / EU, but which could generate ignition sources.

Regarding the methods that can be applied to perform an explosion risk assessment, at present, there is no generalized, recognized method for its assessment, but regardless of the method applied, it is necessary to determine the probability of an potentially explosive atmosphere, together with the appearance of an efficient ignition source and the magnitude of the foreseeable consequences. In principle, the risk assessment comprises four stages:

- hazard identification;
- risk estimation;
- risk assessment;
- analysis of risk reduction options.

Assessment of the products conformity with the essential health and safety requirements of the ATEx Directive 2014/34 / EU for placing on the market

In accordance with Directive 2014/34 / EU, the placing on the market and / or putting into service of products to be used in potentially explosive atmospheres produced by combustible dusts is permitted only if they do not endanger the safety and health of persons, animals or of the environment, provided that their installation and maintenance is appropriate and the use is in accordance with their intended use. In order to meet these conditions, the products must meet the essential health and safety requirements (EHSR) of Annex 2 of the Directive that apply to them, taking into account their intended use.

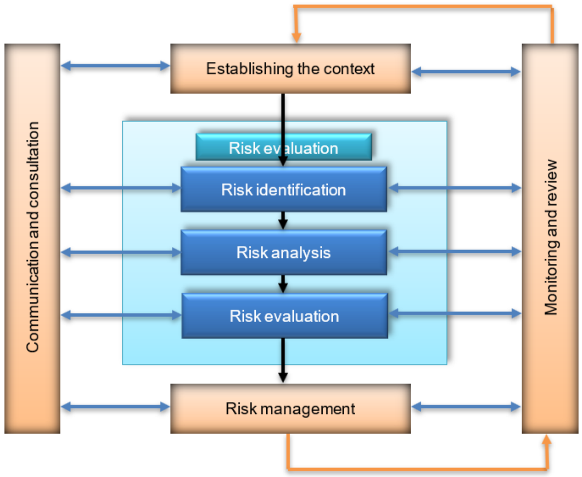
The existing non-binding harmonized standards at European level are the only documents which ensure the presumption of conformity for products in the Ex-field to be placed on the European market. At the same time, manufacturers of Ex equipment may decide whether, in order to ensure product conformity, they use only existing European national standards or use other standards and technical specifications considered relevant to cover essential health and safety requirements.

In this regard, the equipment manufacturer should take the following actions:

- to make the risk assessment;
- to define the requirements of the equipment to be used in the potentially explosive atmosphere, as well as of the safety and control devices that are not located in the explosive atmosphere, but that contribute to the safe operation of the equipment in the explosive atmosphere;
- to define, if deemed necessary, additional explosion protection measures, following the conclusions drawn from the risk assessment;

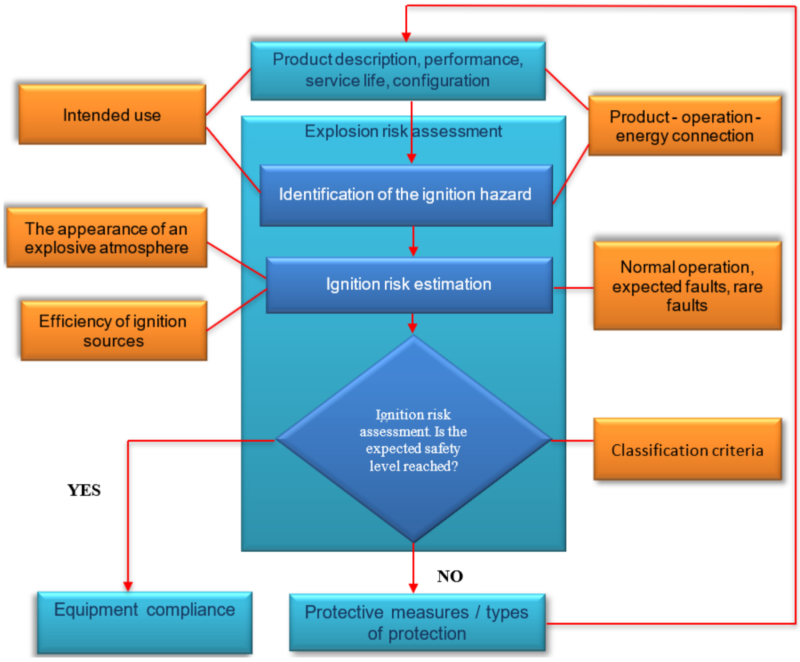
➢ to produce equipment that has the same requirements, i.e., is intended to be used under the conditions defined during the risk analysis and in accordance with Directive 2014/34 / EU.

The risk assessment by the manufacturer of an equipment shall be limited to the assessment of the ignition hazard of that equipment (as part of the risk of explosion), or the control function for a protective or safety device (see SR EN 1127-1: 2019). For the assessment of the ignition risk, regarding the design of the equipment or components, we can use the principles and guidelines for risk management defined in SR ISO 31000: 2018, presented in the following figure:



The risk management process according to SR ISO 31000: 2018

By customizing these principles and guidelines, according to the risk assessment methodology described in SR EN 15198:2008, we obtain the customized risk management process for explosion risk, which is presented below:



Logical diagram for the assessment of the risk of ignition when designing the equipment or component

Analyzing the logic diagram for the ignition risk assessment, we can conclude that this assessment includes the following steps:

- product description in terms of performance, configuration, service life, etc.
- identification of ignition hazards;
- estimation of the ignition risk;
- the actual assessment of the ignition risk.

Therefore, by applying the ignition risk assessment procedure when designing the equipment or component, the level of safety can be defined, which allows the classification into categories according to the appropriate criteria.

Personal contributions to the explosion risk assessment for the placing on the market of products for potentially explosive atmospheres. Development of test methods for enclosures to assess compliance with ATEx requirements for use in combustible dust atmospheres

Considering that, in general, combustible dusts present a risk of fire, and when mixed with air at certain concentrations presents an explosion hazard, if an efficient source of ignition is also present, it is absolutely necessary that the technical installations in which the production, handling or storage of such combustible dusts takes place must be designed, used and maintained in such a way that any release of combustible dusts which could give rise to a potentially explosive atmosphere is kept to a minimum.

As, in some situations, due to the nature of the technological process, the probability of a potentially explosive atmosphere generated by the dust / air mixture cannot be eliminated, it is necessary to adopt measures to prevent the occurrence of a source of ignition, by using technical equipment specially manufactured for this.

In accordance with the specific requirements stipulated in SR EN 60079-0: 2018, in areas where combustible dust is present, may be used technical equipment and Ex components which are protected by the enclosure and which have a limited maximum surface temperature.

In the first part of subchapter 3.3 I described the principle on which the protection against dust ignition by enclosure is based and I identified the requirements that must be met by electrical equipment with level of protection *ta, tb* and *tc*, after which I reviewed the normal degrees of protection provided by the equipment enclosures.

In the last part of subchapter 3.3 I presented the personal contributions to the development of laboratory tests for testing the protection against dust and water penetration inside the enclosures of equipment used in explosive atmospheres.

Thus, for the evaluation of the conformity of electrical and non-electrical equipment with the requirements of ATEX Directive 2014/34 / EU, transposed in GD 245/2016, as they are established in the harmonized standards under ATEX Directive, the certification body INSEMEX-OEC, accredited by RENAR (Certificate of Accreditation ON 046 and notified in Brussels with NB No 1809 must carry out evaluations based on the results of tests carried out in competent laboratories. The group of testing laboratories INSEMEX GLI is the main provider of laboratory testing services for the certification body, being accredited by RENAR (accreditation certificate no. LI 347) regarding the competence to perform specific tests.

Among the tests to be performed for the certification of products used in potentially explosive atmospheres are those to determine the degree of protection of equipment enclosures against the ingress of dust and water inside, called the normal degree of protection IP code. In accordance with SR EN 60529: 1995, in order to be able to meet all requests for testing the enclosure protection, the laboratory must have specific test equipment, of which it can be mentioned: access gauges, dust protection system, dust test system protection against drops of water falling vertically, installation for checking protection against water falling in the form of rain and against water splashes, apparatus for checking protection against water jets.

From the analysis performed in 2018 on the existing facilities in the ENExEMEIP laboratory where I work, it was found that the laboratory has an access gauge kit, a dust chamber with a volume of 0.8 m^3 and a device for checking protection against water jets - spray nozzle.

As we could not carry out the tests to determine the second characteristic figure 3 and 4 because we did not have the necessary equipment to verify protection against water falling in the form of rain and water splashes, it was decided to include it in the development program laboratory solving this problem. In addition, due to the fact that the volume of the dust testing chamber did not allow the testing of equipment with larger dimensions, which was also noted by external auditors in assessing the competence of the laboratory, to the development project was added also the acquisition of a new dust testing chamber.

In this sense, being part of the research and development team of the laboratory, supported by the NUCLEUS Program, I contributed to establishing the technical and performance requirements of the test stands, their experimentation, as well as the implementation of new tests in the laboratory quality system. regarding the validation of tests and the development of test procedures.

Thus, during 2018, two experimental stands were purchased and put into operation through the Nucleus program *PN 18 17 02 01 - Research on enclosure protection for electrical and non-electrical equipment for environments with a risk of explosive atmosphere*, as follows:

- A stand through which the determination of the first characteristic figure, IP 5X and IP 6X, is made, regarding the partial and total protection against the penetration of dust inside the housings of large equipment. This stand is in the form of a dust chamber with an internal volume of 8 m^3.


Standard metal container


Dust chamber


Control room


Control panel

Next is presented the performance of a test performed by a team that is part of LENExEMEIP within INCD INSEMEX Petrosani, on an equipment enclosure by using the dust chamber, to determine the characteristic figure IP 5X / IP 6X.

The testing equipment uses talcum powder with a grain size of less than 75 µm, in the amount of 25 kg, in accordance with the provisions of the test standard. Regarding the verification of the granulometry of the talcum powder, a 75 µm square mesh sieve and a 50 µm wire will be used, which is part of the equipment supply. The distribution of talcum powder will be made by direct discharge of 12.5 kg of talc in each of the two collecting funnels of the equipment. The spill will be done carefully at approx. 1m away from the doors so as not to clog the section openings.

The principle of operation is as follows:

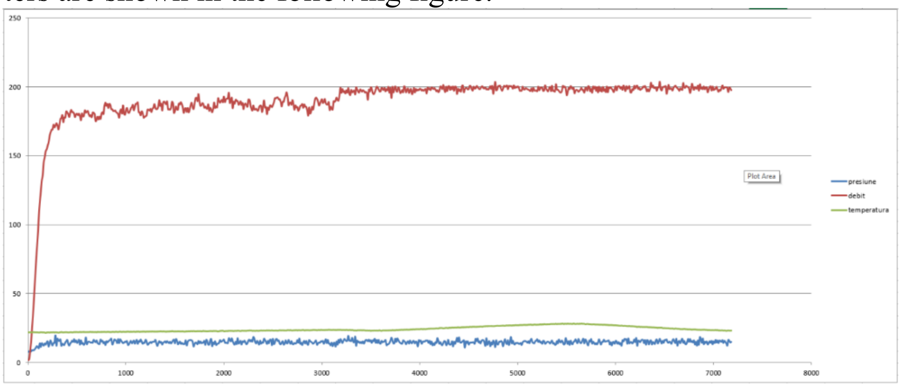
- Place the talcum powder in equal quantities in the 2 funnels of the vibrating hopper.
- The funnel is provided with a vibrator that has the maximum amplitude towards the absorption openings of the indoor air, and during the vibration there is a movement of throwing the talc upwards, simultaneously with its movement towards the back of the hopper (to the operator's room)
- From behind the hopper, two jets of injected air regularly start from the funnel, which bring the talc back to the front of the hopper. At the same time, these jets direct the suspended dust towards the absorption openings and upwards towards the main jet, swirling in the chamber.
- In front of the hopper, in the funnel there are 2 suction holes, to create the main vortex jet. On the route, in the operator's room there is also a battery for heating this jet, which serves to thermostat the enclosure, as well as to dry the dust in recirculation. Once the talc is brought in suspension, it is taken up and maintained in the air, for the period of a vibration cycle, by the main turbulent jet.
- The housing of the equipment to be tested is located in the center of the testing chamber, by direct placement on the two metal sleepers.

After 82 volumes of air had been passed through the enclosure for two hours of operation, the dust chamber was switched off and, after the dust had been completely deposited (photo 3.8), the equipment enclosure was opened and visually examined. It was found that there is no dust inside the enclosure (photo 3.9), for which the following conclusion was drawn: *the enclosure provides a normal degree of protection IP 6X and is suitable for total protection against dust penetration*.

Equipment enclosure (exterior)

Equipment enclosure (interior)

The following parameters can be monitored and recorded in real time via the control, acquisition, processing and recording software: temperature, flow and pressure. Real-time recordings of these parameters are shown in the following figure.



Test parameter records

- A stand that determines the second digit IP X3 and IP X4, in terms of protection against water falling in the form of rain, respectively against water projections through an oscillating tube.

Water protection test stand for equipment

Following the study carried out on the test methods and the realization of the two test stands, the Test Procedure PI 55 - DETERMINATION OF THE NORMAL DEGREE OF IP PROTECTION (both figures) was revised, which was sent to the quality assurance department for integration in GLI quality management system, ENExEMEIP laboratory, for accreditation by RENAR.

The test methods and the associated procedure were implemented within the quality system of the INSEMEX-LIEx laboratory group, RENAR accredited.

The test methods are applicable at national and international level for determining the normal degree of IP protection (IP 5X / IP 6X and IP X3 / IP X4 respectively).

CHAPTER 4

CASE STUDY REGARDING THE EXPLOSION RISK ASSESSMENT OF A BUCKET ELEVATOR IN ORDER TO COMPLY WITH THE ATEX REQUIREMENTS FOR PLACING ON THE MARKET. PERSONAL CONTRIBUTIONS REGARDING THE EVALUATION PROCEDURE

The case study presented in Chapter 4 is designed and conducted as a guide for the explosion risk assessment in bucket elevators, and is intended to be a useful guide for both equipment manufacturers to be able to fulfill their obligations regarding the assessment compliance of the product with the requirements of the ATEx Directive, as well as for third party evaluators involved in the evaluation process of those products.

In the case of bucket elevators, as in the case of other technical equipment, for a correct risk assessment, it is necessary to start from the principles underlying fire and explosion prevention and explosion protection. Thus:

- prevention is based on avoiding efficient ignition sources, which is achieved either by eliminating ignition sources or by detecting them;
- explosion protection is based on the application of rules for ventilation, suppression or isolation of the explosion, specially adapted for bucket elevators. These specific rules may be based on agreed testing methods.

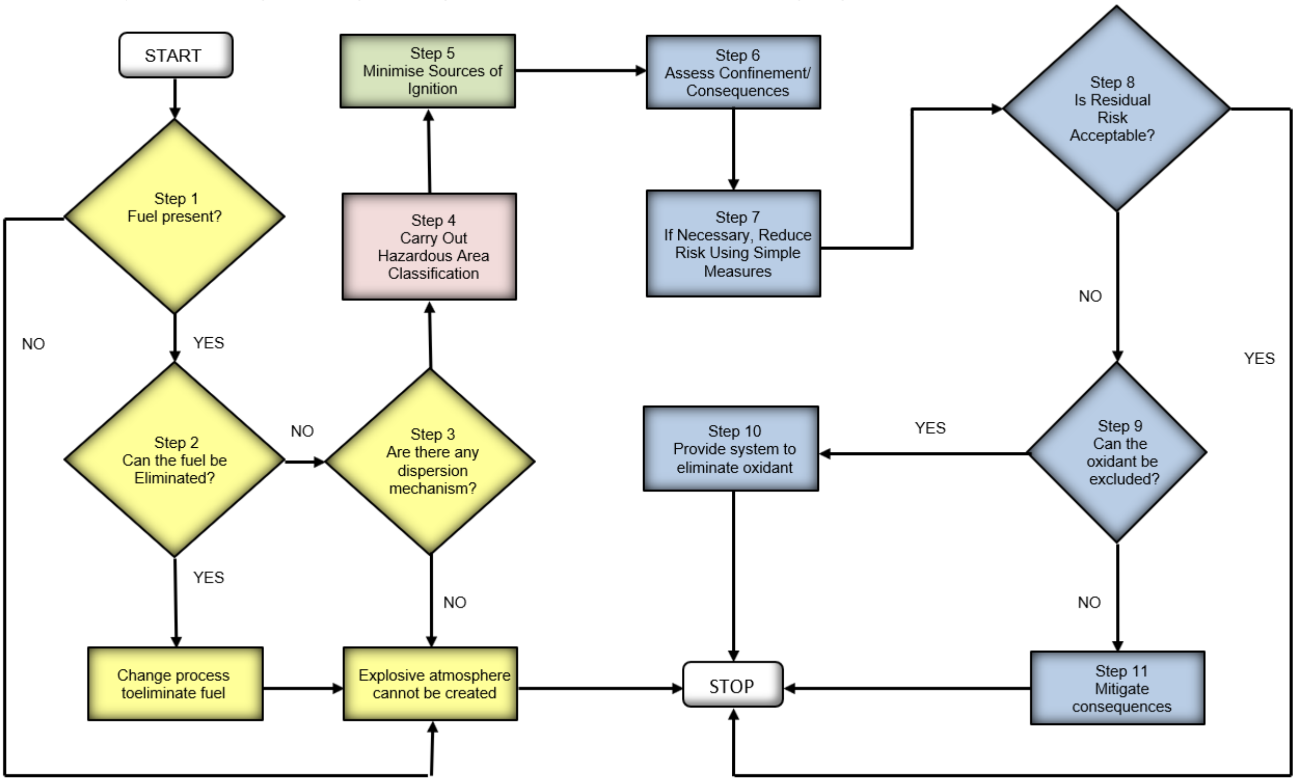
The most common sources of ignition are the result of mechanical problems, such as, for example, friction between the belt and the housing, heating of the rotating mechanical parts on the lift head and the funnel, impact between damaged buckets or between them and foreign objects. These mechanical problems can also create explosive atmospheres: impact or vibration will cause dust deposits to form and create an explosive atmosphere. Therefore, even if there is no explosive mixture of air-dust inside an elevator during normal operation, however, due to mechanical problems, they can lead to an explosion.

After a description and a classification of bucket elevators, with the presentation of the main components, we made an analysis of the danger of fire and explosion in their case.

Fire and explosion hazard analysis for bucket elevators

Indeed, an explosion or fire that occurs inside a bucket elevator is a significant hazard due to the effects produced by the flame and / or the pressure developed on the environment, effects materialized by damage to the bucket elevator itself, damage to related equipment and by affecting the staff serving it. The consequences of igniting dust may be a smouldering fire, a blazing fire, an explosion or a propagating explosion. Following a dust explosion, there is a possibility that a fire may continue inside or outside the bucket elevator.

In principle, the analysis of the danger of fire and explosion in the case of a bucket elevator can be done by following the logic diagram shown in the following figure.



Logical diagram for fire and explosion risk analysis

Explosion hazards are closely related to the presence of explosive atmospheres and the presence of potential sources of ignition.

The possibility of a potentially explosive atmosphere depends very much on the product involved and the operating conditions of the bucket elevator. Thus, we analysed two possible situations in which we took into account the average particle size of the dusty product being transported, as well as the nature of the transported products.

Regarding the possibility of the existence of ignition sources, we analysed the way they appear. Thus, in addition to the ignition sources indicated in SR EN 1127-1, there are also ignition sources related to other influences, namely:

- ✓ the ignition sources introduced from the connected equipment must be taken into account by the end user. Typical examples are hot, incandescent products, embers and / or explosions from connected equipment, etc.
- ✓ external ignition sources due to smoking, maintenance, welding, cutting, etc. must be considered by the end user. These should be prevented through organizational measures.
- ✓ the sources of ignition that may arise from the transported product must be taken into account: e.g., by self-heating in warehouses, inside the bucket elevator

It should be noted that ignition sources can also be created by the bucket elevator taken as a whole, mainly due to the presence of electrical equipment, drive systems and bearings.

Fire hazards

In addition to the danger of explosion, a fire hazard that had to be considered is represented by the products and combustible materials inside the bucket elevator. Vertical orientation and closed construction are favourable factors for fire propagation and unfavourable for fire control.

When assessing the fire hazard of bucket elevators, the combustion characteristics of the combustible materials used (e.g., belts and buckets), the materials to be transported and the dust that is generated during transport must be known in the first place. For the evaluation of the dust, the combustion class (BZ), the ignition temperature, as well as its self-ignition characteristics can be used.

Fire and explosion prevention. Protection of bucket elevators

In principle, fire and explosion protection is based on the adoption and implementation of the following measures:

- prevention of deposits of combustible dusts and powders, as well as prevention of the formation of explosive mixtures;
- prevention of ignition sources.

If prevention is not sufficient, additional fire-fighting and / or explosion protection measures (explosion isolation, ventilation and suppression) need to be taken.

Fire protection can be achieved either manually or by using automated fire detection and extinguishing systems.

Explosion prevention and protection is achieved by preventing the formation of explosive atmospheres and / or by preventing the appearance of ignition sources. The formation of explosive atmospheres can be prevented by taking appropriate measures such as:

- dust removal systems in the loading, transfer and unloading stations;
- transport speeds as low as possible;
- avoiding as much as possible the surfaces where dust deposits can form;
- avoiding the return of the transported material;
- removal of deposits and dust deposits by using adequate evacuation systems;
- binding of dust by using for example water or oils that have a high boiling point and do not have volatile constituents;
- periodic cleaning.

With regard to the prevention of ignition sources, we have presented in tabular form recommendations for the safe use of bucket elevators that are intended for the transport of combustible dust products, as well as prevention measures for ignition sources introduced or acting from the outside to become effective.

Example of ignition hazard assessment in the case of a bucket elevator

The ignition risk assessment is performed for a bucket elevator designed to be used in places located inside a building where a potentially explosive atmosphere generated by the fuel / dust mixture is expected to form, the area being classified as Zone 22 outside the elevator, a Zone 20 being present inside it.

The electric drive motor of the analysed bucket elevator has been certified by a notified body as Category 2 equipment, being suitable for operation in the potentially explosive atmosphere created around it.

The analysed bucket elevator is designed to transport fuel dust / powder vertically. The ignition sensitivity of the combustible powder is assumed to be very high and therefore all potential sources of ignition which under certain conditions may become effective sources of ignition and which could initiate an existing potentially explosive atmosphere have been considered. at a time. Depending on the ignition sensitivity of the actual powder carried by a bucket elevator, some ignition sources may not be relevant.

The bucket elevator contains two wheels fixed on their axles, which rotate in two bearings each. The bearings are mounted directly on the housing. The wheel in the lift head is driven by an electric motor with a rated power of 10 kW by means of a gearbox and a rubber coupling. A non-return mechanism is also installed in this place to prevent the bucket elevator from rolling backwards. The wheel axis at the base of the elevator can be adjusted manually to keep the belt under tension, which must be fireproof and antistatic. The surfaces of both wheels are rough to increase the grip of the belt. The bucket elevator is made of carbon steel with carbon steel buckets. The speed of the bucket elevator is 2 m / s. There are no light metal or plastic parts on display. The drive roller weighs 60 kg. The bucket lift is also equipped with a slip detection device by monitoring the number or rotations, and if it is below a certain value, the electric drive motor is switched off.

In the final part of chapter 4 we made a model for assessing the risk of ignition according to SR EN 80079-36: 2016 in the case of the bucket elevator described above, as an example, for each of the following components of this elevator:

- rollers (wheels, drums)
- bearings
- axles
- band
- cups.

It should be noted that for auxiliary equipment connected to the bucket elevator, such as the coupling, the gearbox, the brake and the electric motor, the ignition risk assessment shall be carried out in accordance with the relevant standard applicable to these components.

CHAPTER 5
ASPECTS REGARDING THE PROCESS OF ASSESSING THE RISK OF INITIATION OF AIR / DUST ATMOSPHERES BY ELECTROSTATIC DISCHARGES

Production, storage and discharge of electrostatic charges

Electrostatic charges are formed and built up as a result of electrisation mechanisms, of which contact electrisation is the most frequently encountered. Two materials of different nature that are brought into contact and then separated, will carry electrostatic charges equal in size and of opposite signs.

Similarly, another component of the electrisation mechanism is induction electrisation, when the conductive materials can be charged with static charges of electrostatic nature, from a nearby charged object. Products/materials can thus get transfer charges, either directly, from other objects, or by influence, from a stream of ions.

Electrostatic charges built up on a solid or on a liquid are dangerous only if they are transmitted (discharged) to another body or to the earth. These discharges vary a lot as type and degree of potential initiation.

After separation during the electrostatic charging process, the charges can rapidly recombine, either directly, by contact, or through the earth. The charges from a non-conductor are retained due to the material itself. But in order for a conductor to stay charged, it has to be isolated from other conductors and the earth.

Static electricity discharges vary a lot by type and degree of potential initiation.

Spark discharges are discharges that occur between two conductors (solid or liquid).

"Corona" discharges take place in sharp areas or at the edges of conductors. The **"Corona" discharge** can occur when a grounded conductor, which has sharp areas, is moved in the direction of a heavily charged object or if its potential is greatly increased.

Brush discharges can occur when round conductors (as opposed to sharp ones), connected to the earthing network, are moved to poorly loaded, poorly conductive objects. This type of discharge can occur, for example, between a person's finger and a plastic surface.

Propagation brush-type discharges are discharges between the two surfaces of a sheet (layer) of high-resistivity material with a high dielectric strength, strongly charged with charges of opposite polarity.

Cone discharges can occur in large silos or containers when filled with a heavily loaded (weakly conductive) dust (a high load density area is generated inside the dust pile)

A summary of incendivity of the different types of discharges is presented in the following table:

Type of discharge	Incendiveness		
	Gas, vapors		Dust
	MIE < 0.025 mJ	MIE > 0.025 mJ	
Spark discharge	+	+	+
"Corona" discharges	+	-	-
Brush discharges	+	+	-
Propagation brush-type discharges	+	+	+
Cone discharges	+	+	++
Lightning discharge	+	+	+

\+ initiation is possible / - initiation is not possible

Among the measures to prevent static discharges can be mentioned the following:

- earthing;
- use of appropriate materials;
- antistatisation of materials;
- choosing the appropriate constructive form (surface, distance from the conductive elements connected to the ground, thicknesses of non-conductive materials);
- avoidance of dangerous frictions (limitation of the speed of movement to the lanes or of the speed of flow through pipes);
- environmental conditions (high humidity);
- use of load neutralizers.

Ignition risk assessment of explosive atmospheres by electrostatic discharges

Assessing the occurrence and determination of the incendivity of electrostatic discharges in different real situations is the most important and the most difficult step in the analysis of the dangers created by electrostatic charges.

The data required for a reliable analysis are:

- accurate knowledge of the properties of the potentially explosive mixture that may be present;
- the strengths or conductivities of the individual substances, devices, packaging, materials and equipment used;
- the volumes and geometric arrangement of the installations and technical devices, as well as
- precise knowledge of the existing ground drainage conditions and the equilibrium conditions of the potential.

Thus, an explosion risk assessment must take into account the probability of the formation of electrostatic charges and their discharge to both the equipment and the product or material.

Knowing the flammability of the discharge (i.e., the amount of energy released) and the sensitivity of the existing potentially explosive atmosphere, as characterized by the minimum MIE ignition energy, it can be determined whether the ignition occurs or not.

In the subchapter **protection measures against combustible dust / air explosions initiated by static electricity** we presented the measures that can be taken, namely:

- ❖ explosion prevention (prevention of the formation of explosive dust / air mixture and avoidance of efficient ignition sources)
- ❖ protection against explosions (measures to prevent the dangerous consequences of an explosion)

I also presented several events in which, due to the less rigorous implementation of technical measures or non-compliance with work or maintenance instructions, there were explosions or fires with serious consequences. We placed particular emphasis on identifying the causes that led to the events, as well as on finding and choosing appropriate measures whose adoption could have prevented the occurrence of these events. Thus, we have the following situations:

- filling a mixer with plastic powder;
- grinding a product moistened with solvent;
- emptying large bags (FIBC);
- explosion in a coal dust exhaust system;

Explosion risk assessment on ignition of explosive dust atmospheres by electrostatic discharges to silos. Personal contributions to the development of laboratory tests for the determination of the minimum ignition energy in the case of explosive dust / air mixtures

The ignition sensitivity of a dust cloud is characterized, as for any other fuel, by its minimum ignition energy (MIE). The most common electrostatic discharges in the industry have an energy that is normally less than 10 mJ. Therefore, materials with a minimum ignition energy value of 10 mJ or less are considered to be the most critical.

Different forms of discharges, such as sparks, brushes and propagation brushes, can lead to ignition hazards depending on the discharge energy and the minimum ignition energy of the dust cloud. The appearance of both spark and brush discharges can be eliminated, ensuring that the surface resistance is below 10^{11} Ω and above 10^{8} Ω. Surface resistance can be reduced and brought to the limits mentioned above, using antistatic additives. But there are two problems associated with this measure: the antistatic effect is often dependent on the relative humidity of the environment and antistatic additives are sometimes absorbed by the product in contact with the treated surface.

Propagation brush-type discharges can be eliminated by using conductive materials or insulating materials with low dielectric strength in all places, which are potential places for the accumulation of high surface loading densities.

Brush discharges will not occur if the fault voltage on a non-conductive layer or sheet is less than 4 kV.

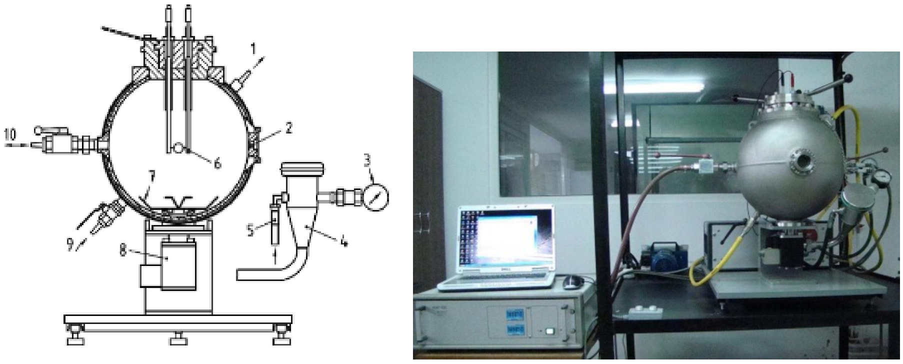
Corona discharges are not considered incendive for dust.

Two other types of discharges - cone discharge and lightning discharge - are characterized by the fact that they can occur only in specific processes.

In the case of silos, the ignition risk assessment process must take into account that hazardous electrostatic charges can accumulate on both the bulk material and the silo wall.

In subchapter 5.4.2 we presented a model for assessing the risk of ignition of the mixture of combustible dust / air in silos due to electrostatic discharges, in the form of logic diagrams. The choice of one of the 3 logic schemes presented to perform the ignition risk assessment is made according to the resistivity value of the bulk material.

In subchapter 5.4.3 we presented the research carried out in the ENExEMEIP laboratory within INCD INSEMEX regarding the development of tests for finding the minimum ignition energy in case of explosive dust / air mixtures. We considered two methods, an estimation method that uses the KSEP-20l installation and can be used as a method of interpreting the minimum energy, and the standardized (quantitative) method that uses the MIE-D 1.2 installation which is currently the reference method for determining the minimum ignition energy.



KSEP-20 test installation

MIE-D 1.2 equipment

I also presented the results of tests performed in the LENExEMEIP laboratory within INCD INSEMEX Petroșani to determine the minimum ignition energies of some powders, using the estimation method, as well as a comparative analysis of the results obtained to determine the minimum energy of ignition by applying the two methods, on the same type of dust.

6. FINAL CONCLUSIONS. SYNTHESIS OF PERSONAL CONTRIBUTIONS

FINAL CONCLUSIONS

In all activities involving flammable substances which may generate explosive atmospheres, an explosion may occur if an explosive atmosphere is present at the same time as an efficient source of ignition. There are a multitude of chemicals present in the form of raw materials, intermediates, end products and even waste resulting from normal production processes which, at certain concentrations in the air, can lead to an explosive atmosphere. Virtually all industries are affected to some extent, as the hazards arising from the presence of explosive atmospheres are present in many technological processes and operations.

Given that explosions can result in major material damage and even death, the explosion risk assessment process and then setting appropriate measures to limit or reduce it to a level that can be accepted in accordance with the rules and standards in force, is of major importance in ensuring the safety and health of people and property.

An essential element in the process of assessing the risk of explosions in workplaces where potentially explosive atmospheres may occur is represented by installations operating in this environment. These installations need to be designed, constructed, installed and maintained in such a way that they are not capable of generating sources of initiation. Therefore, measures must be taken to prevent the occurrence of sources of ignition that they could generate.

The studies I carried out in the research activity and continue to carry out at INCD INSEMEX focused on three main directions, namely:

- Development of explosion risk assessment methods;

- Determination of the ignition sensitivity of various explosive dust / air mixtures, by performing the laboratory tests necessary to determine their explosive characteristics: maximum explosion pressure, minimum ignition energy, lower explosive limit, etc.
- Determining the protection performance of technical equipment to prevent the occurrence of efficient ignition sources for explosive atmospheres.

With regard to the determination of the ignition sensitivity of various explosive dust / air mixtures and the determination of the protective performance of equipment to prevent the occurrence of effective ignition sources of explosive atmospheres, the aim was to implement high-performance test methods in accordance with international principles and practices, through the use of state-of-the-art equipment, in order to be recognized nationally and internationally.

The following aspects were taken into account when developing the new test methods:

- The variety of types of materials to be tested in order to evaluate them and for which it is necessary to make specific testing devices;
- The variety and complexity of the tests to be applied to the products in accordance with the requirements of European standards.
- The obligation to use precision devices in the tests, which are calibrated to the prescribed parameters;
- The obligation to ensure special test conditions regarding the environment in which the test is performed, the pre-conditioning of the materials that are subjected to those tests, as well as the use of hazardous materials;
- To permanently ensure the required level of trust;
- Ensure traceability for standards.

The equipment and software used to perform the tests, calibration and sampling must be capable of achieving the required level of accuracy and be performed in accordance with the requirements and specifications relevant to those tests and / or calibrations. In this regard, it is necessary to continue to purchase state-of-the-art research equipment in order to further develop laboratory tests.

PERSONAL CONTRIBUTIONS SYNTHESIS

The personal contributions, materialized by the results obtained following the research carried out and presented in the doctoral thesis, refer mainly to:

- Development of methods for assessing the risk of explosions due to ignition of explosive dust atmospheres by electrostatic discharges;
- Development of methods for assessing the risks of ignition in the case of bucket elevators;
- Development of tests for the verification of protection against the ingress of dust and water into enclosures and / or equipment intended for use in environments with potentially explosive dust / air atmospheres;
- Development of laboratory tests for the determination of explosive properties for explosive dust / air mixtures.

By the developed method of assessing the risk of explosions due to ignition of explosive dust atmospheres by electrostatic discharges, as presented in Chapter 5 of the paper, I identified all the factors that determine the risk of initiation of potentially explosive atmospheres of air / dust after electrostatic discharges. We also performed an assessment of the risk of ignition of atmospheres of combustible dust / air in silos due to electrostatic discharges, by presenting logic diagrams through which an analysis can be performed if the bulk material can be electrostatically charged to a hazardous value during loading in the silo or in containers.

To develop the method for assessing the risk of ignition in case of bucket elevators, I made an analysis of the most common types of elevators and identified all sources of ignition that may occur during the operation of a bucket elevator, namely: electrical sparks, hot surfaces of electrical equipment, electrostatic discharges, mechanical sparks, hot surfaces due to friction and friction, hot flames and gases including hot particles from outside the elevator, atmospheric electric discharges, etc. Also, at the end of the chapter I made a tabular model to assess the risk of ignition in the case of a bucket elevator, taking into account the following components of this elevator: rollers (wheels, drums), bearings, axles (axles), drive belt of buckets, buckets.

Regarding the development of test methods applied to determine the protection against dust and water inside the enclosure of technical equipment that are intended for use in environments with a risk of explosive atmospheres and the stands necessary for the application of these methods, I contributed to the establishing the technical and performance requirements of the test stands, their experimentation, as well as the implementation of new tests in the laboratory quality system regarding the validation of tests and the development of test procedures. Thus, the Test Procedure PI 55 - DETERMINATION OF THE NORMAL DEGREE OF IP PROTECTION (both digits) was revised, a procedure that was sent to the quality assurance department for integration in the GLI quality management system, ENExEMEIP laboratory, for accreditation by RENAR, and the test methods were implemented within the quality system of the INSEMEX-LIEx laboratory group, accredited by RENAR.

To validate the applied methods, the practical tests were performed in the ENExEMEIP laboratory within INCD INSEMEX Petroșani, as follows:

- test on an equipment enclosure by using the dust chamber to determine the IP 5X / IP 6X characteristic figure of that enclosure;
- test on an equipment enclosure using the automated stand to determine protection against water falling in the form of rain (IP 3X) and against water splashes with the oscillating tube (IP 4X);

I also made personal contributions to the development of laboratory tests to determine the explosive properties of explosive dust / air mixtures. Thus, we have identified the appropriate (state-of-the-art) equipment for performing tests to determine the minimum ignition energy according to existing standardized methods at European level. In this regard, I performed comparative tests to determine the minimum ignition energy of the mixture with air and atomized mycelium powder (nystatin), using the KSEP-20l stand, respectively the new MIE-D 1.2 stand, interpreted the results obtained and identified the factors ensuring the repeatability and reproducibility of the tests, such as laboratory accreditation requirements, in accordance with standard EN ISO 17025. As the calibration of this stand cannot be done by usual means at national level, it is necessary to validate the tests by performing interlaboratory tests. In this regard, we have signed up for an ongoing calibration round, being organized by CESANA AG in Switzerland, to which participate more than 30 laboratories from several countries.

Therefore, the analysis of the technical solutions for the realization of the test stands, the actual realization and their experimentation, as well as the implementation of the new techniques and methods in the test procedures within the laboratory for the accreditation of the tests, are personal contributions that currently apply in ENExEMEIP test laboratory within INCD INSEMEX Petroșani.