EVALUATION OF THE AUTO-IGNITION TEMPERATURE OF DUST ACCUMULATIONS - A CASE STUDY OF WASTE FROM THE AUTOMOTIVE INDUSTRY

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Abstract: The phenomenon known as spontaneous combustion occurs when combustible organic powders are heated by gradual oxidation through an air channel (formed by an air depression) through the dust aggregate. The oxidation of combustible powders is the reaction of these powders with air oxygen to form carbon dioxide, carbon oxide, water, and other gases whose contents are temperature-dependent. Combustible dust can self-ignite based on their chemical composition, the characteristics of their constituent materials, the size and shape of the material mass's particles, and—last but not least—the ambient temperature. Environmentally friendly organic waste is being used for many applications, including building materials, in response to global concerns about sustainability in construction engineering. The difficulty is that, when using these materials, one must ensure the safety associated with the handling of such organic components that are known to have flammable characteristics. This work aims to determine the self-ignition behavior of combustible dust from the automotive industry, in order to be able to take the appropriate measures of protection.

Keywords: Combustible dust, spontaneous combustion, dust accumulation, autoignition temperature

1. INTRODUCTION

According to the Occupational Safety and Health Administration (OSHA) [1, 2, 15, 17], combustible dust is defined as "a fine material that presents a fire or explosion hazard when dispersed in air and ignited." This definition encompasses a wide range of

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organic and inorganic materials that can be reduced to a powder and pose a risk under specific conditions. Examples of combustible dust include metals, wood and wood products, coal and other carbon-based materials, plastics and rubber, flour and other agricultural products, and certain chemicals. The hazard associated with combustible dust arises from its potential to form explosive mixtures with air.

The key to risk assessment lies in accurately determining the flammability of the dust. Combustible dust is a term used to describe fine solid materials with a diameter of 420 microns or less that can cause a fire or explosion when they are dispersed and ignited in the air. This definition is found in both NFPA 654: Standard for the prevention of explosions against fire and dust in the manufacture, processing, and handling of combustible particulate solids, and NFPA 454: Standard for combustible metals, metallic powders, and metallic dust. In addition to particle size, it is important to consider additional elements such as the method of dust dispersion, the availability of ventilation, airflow patterns, potential sources of ignition, and the presence of physical barriers that ensure dust containment or separate work activities. Effective management and eradication of combustible particulate matter is equally vital [3, 4, 16, 19, 20].

Understanding the materials typically associated with dust explosions and fires is crucial for maintaining workplace safety. DustEx Research Ltd.'s latest data reveals that from January 1, 2023, to July 1, 2023, there were a total of 159 fires, 32 explosions, 71 injuries, and 48 fatalities worldwide caused by flammable dust. 82 percent of the injuries and 52 percent of the fatalities were caused by food, metals, and wood processing. Furthermore, there were additional occurrences at establishments that handle pulp and paper, rubber, grass products, graphite and carbon, pharmaceuticals, plastics, and waste treatment. In the first and second quarters of 2023, dust collectors were responsible for 11.5 percent of reported incidents [5, 18, 21, 23].

According to this data, in the last year (2023), combustible dust explosions and dust fires remain prevalent in industries like as wood processing, food production, and metal manufacturing. Sectors such as wood, food, and metal production are particularly susceptible to combustible dust explosions and dust fires.

Autoignition of dust clouds poses a significant safety hazard in various industrial settings, particularly in sectors where fine particulate materials are prevalent. When combustible dust accumulates and becomes airborne, it can form explosive dust clouds. These clouds can ignite spontaneously at specific temperatures without the need for an external ignition source, a phenomenon known as autoignition. Understanding the conditions that lead to autoignition is critical for preventing dust explosions and ensuring workplace safety [6 - 8].

The autoignition temperature (AIT) is a key parameter that indicates the minimum temperature at which a dust cloud will ignite on its own. Several factors influence the AIT, including dust particle size, concentration, and the presence of contaminants. Accurate determination of AIT helps in designing effective dust control measures and safety protocols to mitigate the risk of ignition.

The self-ignition hazard of bulk materials must be assessed through the experimental determination of self-ignition temperatures as a function of volume. Two standardized methodologies are available for this purpose: measuring the self-ignition temperature of a layer of dust placed on a heated surface and determining the self-ignition temperature of dust samples in an oven. The second method may be challenging to employ at times, contingent upon the sample's behavior during these evaluations [9].

The primary reason for self-heating (or potentially self-ignition) is the occurrence of exothermic reactions between oxygen in the air and the molecules present on the surface of combustible dust particles. These reactions take place inside the open space between particles, even under normal temperature conditions. After the release of heat, any quantity of it will increase the temperature inside the dust-air system, hence hastening the reaction between further dust particles and oxygen. The thermal equilibrium of the system depends on the heat generated within the dust mass (amount and surface area of reactive molecules, calorific value) and the heat lost to the environment (thermal conductivity and size of the dust mass, heat transfer coefficient on the outer surface). This balance determines whether the system reaches a thermal equilibrium at a slightly higher temperature or if the temperature of the dust mass increases until self-ignition occurs, caused by inadequate heat dissipation [10, 22, 25].

The common experimental approach used to study the self-ignition behavior of a dust sample is to determine the AIT of dust masses with different volumes. These experiments are carried out in isoperibolic conditions (storage at constant temperatures) inside a heating oven. The dust sample is placed freely in wire mesh baskets of different sizes, using a spatula, without any compression or leveling on top. The baskets have an open at the top and a closed bottom. The mesh size is carefully selected to ensure that the dust remains securely contained within the net, while allowing for the necessary diffusion of oxygen from the oven's air supply system into the dust sample. The volumes used for this case study were: 125 cm^3, 512 cm^3, and 730 cm^3. At the test temperature, the chimneys were positioned in the middle of the preheated oven. When dust is ignited, a fire breaks out. A dust fire has the potential to escalate into a dust explosion. However, the ignition of a dust cloud can result in an explosion that is characterized by rapid pressure changes and the sudden release of heat, unlike a fire. This highly explosive reaction is the cause of the particular dangers linked to a dust explosion [2, 10, 11].

During the test, two temperature measurements are taken. One is the oven temperature, which is measured using a thermocouple placed in the air space halfway between the sample surface and the inner wall of the oven. The other measurement is the sample temperature, which is measured using a thermocouple with its hot junction positioned directly at the center of the sample. If the temperature of the sample increases suddenly and exceeds the oven temperature by at least 60 K after a delay, it is indicative of self-ignition [11, 12, 24].

In the quest for safer and more efficient automotive manufacturing processes, understanding the autoignition temperature (AIT) of combustible dust has become critically important. Despite the widespread recognition of these hazards, there remains a notable gap in comprehensive data on the AIT of various dust types encountered in the automotive industry.

This study aims to experimentally determine the AIT of combustible dust commonly found in the automotive industry, namely the shot blasting powder. Utilizing standardized testing methodologies, we investigate the ignition characteristics of these materials under controlled laboratory conditions. The findings of this research provide valuable insights into the thermal hazards associated with these dusts, contributing to the development of improved safety guidelines and practices. Furthermore, this study will enhance our understanding of the factors influencing dust ignition.

2. MATERIALS AND METHODS

2.1. Materials

There were performed tests to determine the self-ignition temperature for samples of industrial dust, namely the shot blasting powder, collected from an important beneficiary in the automotive field. The sample used was representative and obtained under normal operating conditions of the process.

Shot blasting is a surface finishing technique used to pre-treat or clean the metal before the powder coating is applied. Shot blasting is popular in almost every industry that uses metal, including aerospace, construction, automotive, shipbuilding, rail, and many more. In the process of shot blasting, small abrasive particles made of metal such as aluminum oxide or carbon grit are blasted to the surface in a controlled manner. Smaller shots lead to a smoother, polished finish, while larger shots remove excess forged material. Shot blasting delivers a much more powerful impact on the surface of the workpiece than sandblasting (a process somehow similar, but using gentler abrasives such as organic media, sand, or glass). This effect can generate textured surfaces and shaping that cannot be achieved with sandblasting. The shot-blasting powder is presented in Figure 1.

Figure 1. Shot blasting media

2.2. Experimental method

The experimental setup used to perform the tests follows the standard SR EN 15188: 2021 requirements, as shown in Figure 2.

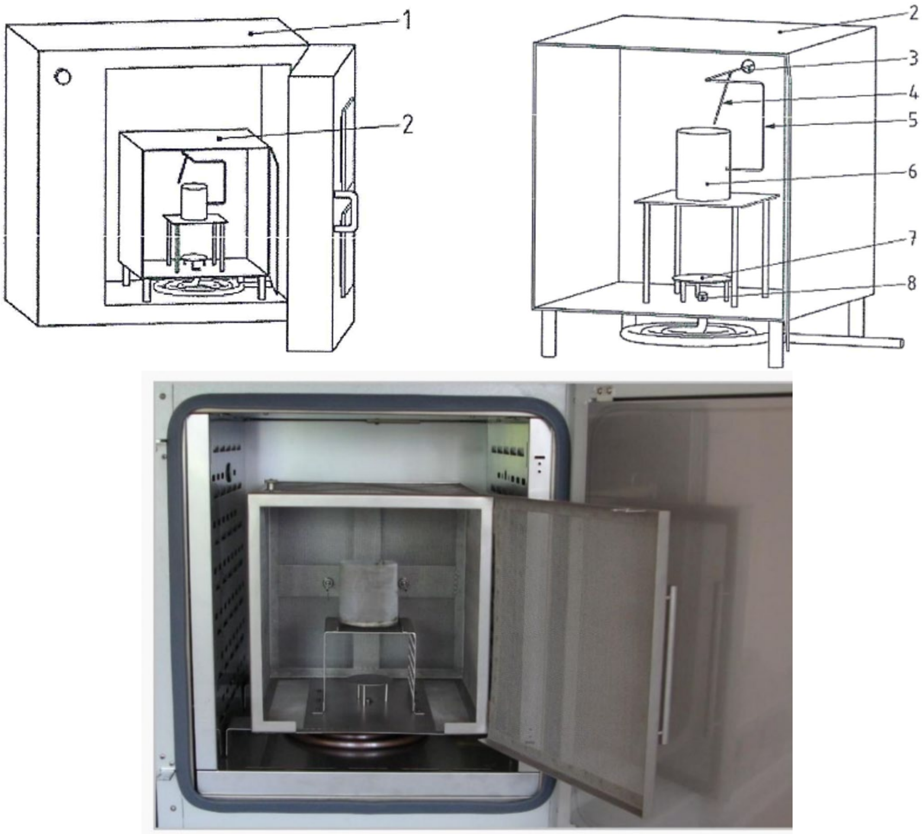


Fig. 2. Experimental assembly for hot steaming tests
1 - heating oven; 2 - inner enclosure; 3 - air outlet, 10 mm diameter air inlet (preheated air, flow); 4 - thermocouple for temperature measurement; 5 - thermocouple for measuring the sample temperature; 6 - wire mesh cylinder, with dust sample; 7 - deflector

To measure and record the temperature of the sample and the oven, thermocouples with a protective coating with an outer diameter of approximately 1 mm and a data acquisition system corresponding to the recording of signals from thermocouples were used.

To determine whether or not self-ignition occurs, there are two methods:

a. When the temperature in the center of the sample rises by at least 60 K above the oven temperature;
b. When the temperature in the center of the sample shows an inflection point, relative to time, if it appears above the oven temperature - Figure 3.

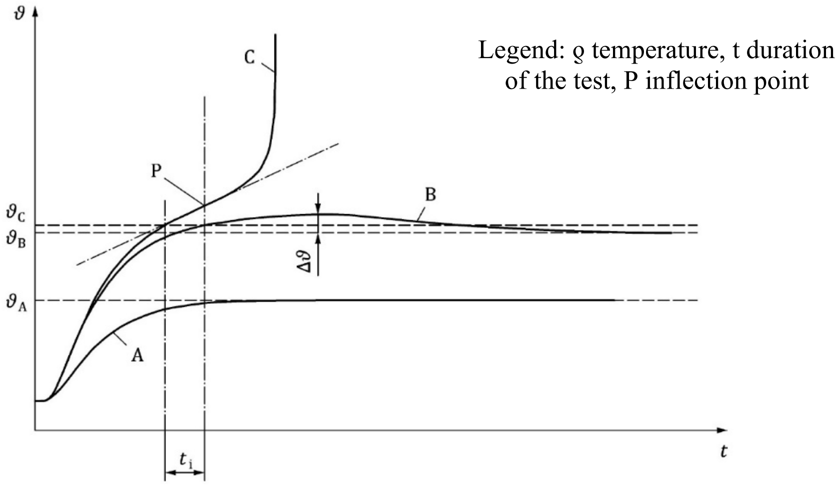


Fig. 3. Ideal time-varying temperature variation curves for dust samples of the same volume at different evaporation temperatures

When working at significantly lower temperatures, the sample temperature will approach asymptotically the oven temperature (curve A).

At higher oven temperatures, significant reactions with oxygen take place in the dust mass, the sample temperature will be temporarily higher than the oven temperature and the self-heating process will start, without igniting the sample. Thereafter, the sample temperature decreases to the oven temperature (curve B).

The heat production in the sample has reached a threshold where it consistently exceeds the heat loss (by heat conduction, convection, and radiation). Following an induction time, the temperature of the sample increases rapidly until it reaches the point of self-ignition, as indicated by curve C. The self-ignition temperature falls within the range of furnace temperatures represented by curves B and C. The time interval between placing the sample in the oven and achieving the steaming temperature, as well as the overall steaming time, were recorded for each test. Furthermore, the time interval between attaining the steaming temperature and ignite was recorded, ultimately reaching the maximum temperature [11, 26, 27].

3. RESULTS AND DISCUSSIONS

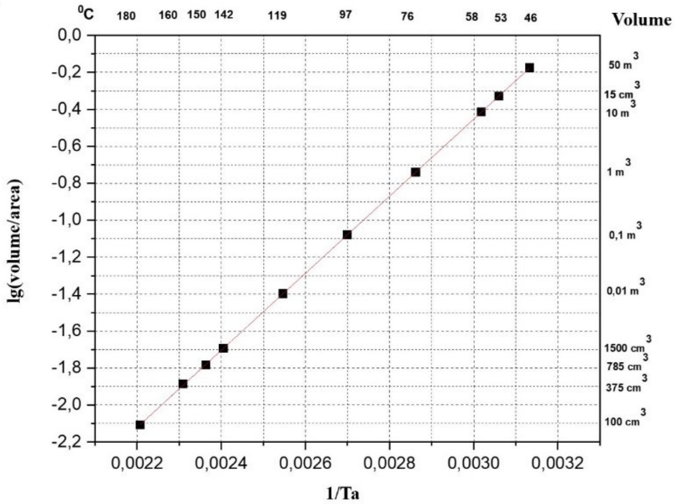
Following the analysis, the results presented in the table below were obtained, as well as the graphs in Figures 4 and 5:

Table 1. **Characterization of the sample. Shot-blasting powder**

Dust volumes tested (cm3)	AIT (°C)	Induction time (hour)
100	180	0,5
375	160	1,1
785	150	1,8

Graph interpretation:

In Figure 4, the Ta variation for several dust volumes is presented, in the form of chart lg(V/A) function of 1/T. The line that crosses the Ta values, separates the equilibrium regions from the unstable regions for the dust volumes. Self-ignition occurs in the region above the curve. For the analyzed dust sample, it resulted that a cylindrical volume of 1 m^3 has an auto-ignition temperature higher than 76°C.

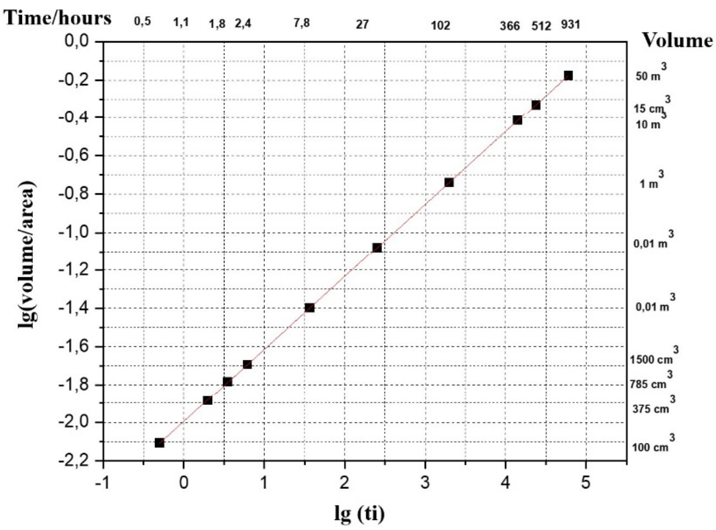


Legend:
lg (V/A),
V – the volume of the test sample,
A – the area of the test sample,

lg (ti/1h),
ti – induction time

Fig. 4. Graphical representation of ignition temperatures after Arrhenius

In Figure 5, the induction times required for the critical ignition for different dust volumes were plotted as lg(ti) function of lg(V/A).



Legend:
lg (V/A),
V – the volume of the test sample,
A – the area of the test sample,

lg (ti/1h),
ti – induction time

Figure 5. Dependence of the induction time of combustion (ti) on the volume/surface ratio

From this figure, the induction time for the self-ignition of the dust samples deposited at temperatures over the ignition temperature can be deduced. So, for our sample, if this volume of 1 m^3 is stored at this constant temperature, it will take 4 days before an ignition could occur. Self-ignition of bulk dust is caused by the rate of heat production, oxidation and/or decomposition reactions of the dust, which is higher than the rate of heat loss. Generally speaking, self-ignition or spontaneous combustion is limited to the contact of solids with high specific surfaces. Oxygen can react on surfaces in the entire amount, as long as the air exchange is large enough. The oxidation process can begin at room temperature depending on the substance [12 -14].

4. CONCLUSIONS

Using the test stand described in the specific European standard SR EN 15188:2021, tests were performed to determine the self-ignition behavior of some dust waste, common for the automotive industry (shot-blasting powder). The experimental results demonstrated that the investigated dusts are flammable, and based on the graphs produced, safety precautions can be implemented to prevent unintentional fires and explosions.

By integrating the two plots, the maximum duration for which a specific quantity of dust can be accumulated without reaching its self-ignition temperature may be determined. Thus, for a cylindrical volume of 1 m^3 of dust, the obtained auto-ignition temperature was higher than 76°C. If this volume of dust is stored at this constant temperature, it will take four days before an ignition could occur. The safety manager can take appropriate measures to prevent undesirable events based on such values.

The experimental determination of self-ignition temperatures for industrial dust waste is a foundational element in the proactive management of fire and explosion risks. By leveraging accurate and reliable data, industries can enhance their safety measures, protect workers, and ensure compliance with regulatory standards, thereby fostering safer industrial environments.

Acknowledgements

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 PN 23 32 02 01, title: Development of the knowledge level of the explosion parameters of gaseous and hybrid mixtures based on hydrogen, involved in the processes of obtaining and storage, to reduce the explosion risk.

REFERENCES

[1]. OHSA FS3791 – 2015, Combustible dust explosion fact sheet (2015)
[2]. OHSA 3371-08 2009, Hazard communication guidance for combustible dusts (2009)
[3]. https://www.grainger.com/know-how/safety/emergency-response/combustible-dust/kh-combustible-dust-hazards [Accessed 25.06.2024]

[4]. Center for Chemical Process Safety (CCPS), *Guidelines for Combustible Dust Hazard Analysis*. John Wiley & Sons, Inc., Hoboken, New Jersey, USA, 2017.

[5]. https://dustsafetyscience.com/combustible-dust-incident-report/ [Accessed 25.06.2024]

[6]. **Joshi, K.A.; Raghavan, V., Rangwala, A.S.** Influence of confinement geometry on ignition behavior of dust deposits. *Proceedings of the Combustion Institute*. **2013,** 34(2), 2471–2478. https://doi.org/10.1016/j.proci.2012.07.032

[7]. **Dowbysz, A.: Kukfisz, B.; Samsonwicz, M.; Bihalowicz, J.S.** Determination of the Self-Ignition Behavior of the Accumulation of Sludge Dust and Sludge Pellets from the Sewage Sludge Thermal Drying Station. *Energies*. **2023,** 16(1). https://doi.org/10.3390/en16010046

[8]. **Półka, M.; Lepik, P.; Skrizovska, M; Bernatik, A.** Analysis of the chosen thermal and flammability parameters of dried sewage dust, *Journal of Loss Prevention in the Process Industries.* **2023**, 83, https://doi.org/10.1016/j.jlp.2023.105098

[9]. **Nalboc, I.; Prodan, M.; Szollosi-Mota, A.; Suvar, N.S.** Experimental investigation on the self-ignition behavior of dangerous dust accumulations, *MATEC Web of Conferences.* **2024**, 389, 00016. https://doi.org/10.1051/matecconf/202438900016

[10]. **Eckhoff, R.** *Dust Explosions in the Process Industries, 3rd Ed.* Gulf Professional Publishing, Houston, TX, 2003.

[11]. **Wu, D.; Schmidt, M.; Berghmans, J.** *Spontaneous ignition behaviour of coal dust accumulations: A comparison of extrapolation methods from lab-scale to industrial-scale.* Proceedings of the Combustion Institute. 2018, 37(3), 4181-4191. https://doi.org/10.1016/j.proci.2018.05.140

[12]. SR EN 15188:2021 Determination of the spontaneous ignition behaviour of dust accumulations.

[13]. **Calamar, A.N.; Gaman, G.A.; Kovacs, M.; Pupazan, D.; Lorand, T.** *Analysis of pollutant imissions generated by bone meal production*, Quality-acces to success. 2017, 18, 178-183, ISSN 1582-2559

[14]. **Calamar, A.; Toth, L.; Simion, S.; Kovacs, M.** *Research on the advantages of in situ investigation of air quality parameters by means of environmental auto laboratories,* MATEC Web of Conferences. 2020, 305, 00062. DOI: 10.1051/matecconf/202030500062.

[15]. **Dinescu, S., Radu, S. M., Florea, A., Danciu, C., Tomuș, O. B., Popescu, S.** *Possible risks of CO2 storage in underground salt caverns.* Annals of the University of Petrosani Mechanical Engineering, 23, 2021.

[16]. **Tomuş, O. B., Andraş, A., Jula, D., Dinescu, S.** *Aspects relating to the reliability calculation of the cutting-teeth mounted on the bucket wheel excavators used in lignite mining*, In MATEC Web of Conferences (Vol. 290, p. 01020). EDP Sciences, 2019.

[17]. **Radu, S. M., Vîlceanu, F., Toderas, M., Lihoacă, A., Dinescu, S.** *Determining the Level of Structural and Mechanical Degradation of Steel in the Supporting Structure of Mining Excavation Machinery*. Processes, 12(1), 153, 2024.

[18]. **Andras, I., Andras, A., Dinescu, S.** *On the correlation of cutting resistance and physical-mechanical properties of lignite and overburden rocks from Oltenia coalfield.* In Proceedings of the MultiScience—XXX. microCAD International Multidisciplinary Scientific Conference, University of Miskolc, Miskolc, Hungary (pp. 21-22), 2016.

[19]. **Fîță N.D., Radu S.M., Pasculescu D., Popescu F.G.** *Using the primary energetic resources or electrical energy as a possible energetical tool or pressure tool*. International conference KNOWLEDGE-BASED ORGANIZATION, vol. 27, no. 3, pp. 21-26. 2021.

[20]. **Fîță N.D., Barb C, Pasculescu D, Pana L.** *The description and evaluation of technical incident risk on the National Power Grid in the context of power safety growth*. MATEC Web of Conferences, (Vol. 290, p. 12010). EDP Sciences, 2019.

[21]. Handra A.D., Popescu F.G., Pasculescu D. *Utilizarea energiei electrice - lucrări de laborator*, Editura Universitas, Petroşani, 167 pag., 2020.
[22]. Andras, A., Popescu, F. D., Radu, S. M., Pasculescu, D., Brinas, I., Radu, M. A., Peagu, D. *Numerical Simulation and Modeling of Mechano–Electro–Thermal Behavior of Electrical Contact Using COMSOL Multiphysics*, Applied Sciences, 14(10), 4026, 2024.
[23]. Vasilescu G.D., Petrilean C.D., Kovacs A., Vasilescu G.V., Pasculescu D., Ilcea G.I., Burduhos-Nergis D.P., Bejinariu C., *Methodology for assessing the degree of occupational safety specific to hydrotechnical construction activities, in order to increase their sustainability*, Sustainability, Jan 21;13(3):1105, 2021.
[24]. Petrilean, D. C. ;Irimie, S. I., *Solutions for the capitalisation of the energetic potential of sludge collected in Danutoni wastewater treatment plant*, Journal of Environmental Protection and Ecology, Vol.16 No.3 pp.1203-1211, 2015.
[25]. Petrilean D.C., *Elaborating and Analysing the Real Balance of Heat for the Steam Generator RGL 10/DD.* Annals of the University of Petrosani, Mechanical Engineering,Volume 10, 155-160, 2008.
[26]. Petrilean, D.C., Preda, L., Marinescu, D.C., *Real and optimum exergetic balance sheet of helical screw compressor ATLAS COPCO GA 30 CF to reduce energy consumption*, 15th International Multidisciplinary Scientific, GeoConference SGEM 2015, SGEM2015 Conference Proceedings, June 18-24, Book 4, pp. 425-432, Albena, Bulgaria, 2015.
[27]. Petrilean D.C., *Termodinamica Tehnica si Masini Termice*, Editura A.G.I.R., 2010.

This article was reviewed and accepted for presentation and publication within the 11th edition of the International Multidisciplinary Symposium "UNIVERSITARIA SIMPRO 2024