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ISSUES AND INTERPRETATIONS OF THE IGNITION RISK RISED FROM MECHANICAL SPARKS IN EXPLOSIVE ATMOSPHERES

1. INTRODUCTION

An explosive mixture formed by air with combustible gas, within explosive limits, can be ignited by different ignition sources of electrical, mechanical or thermal nature etc.

The mechanical sparks represent ignition sources of a mechanical nature generated by friction phenomena. They are metallic particle resulted from mechanical interaction products between two metallic parts. Depending on the mechanical interaction conditions (light collision, intermittent friction or continuous friction) can produce mechanical sparks in form of particles with high or very high temperature.

In literature are found two theories that explain the mechanism of mechanical spark formation:

- alumino-thermy process where through metallic particles arrive to incandescence as a result of the exothermic reaction between aluminum and iron oxides (rust);
- oxidation ignition and metallic particle burning theory where through metallic particle have a successive oxidation process, through initial temperature which was separated particle, ignition and burning of them under protection of a metal oxide layer formed on the outer surface which allows penetration of the necessary oxygen.

2. ASSESSMENT

Testing the mechanism generating the ignition explosive mixture from mechanical spark, known up to the present, described in the literature, shows the following:

a) Alumino-thermy process (thermal) producing metallic sparks is found both theoretically and experimentally in the case of mechanical interaction like impact and friction between aluminum and alloys with the rusty steel. The thermal theory cannot explain generation of metallic sparks in the case of other industrial metals like Mg, Ti, Fe and their alloys.

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b) Oxidation, ignition and metallic particle burning theory is argumentative in the case of majority industrial metals. According to this theory a significant rising of ignition capacity of the mechanical spark has an oxidation process of the hot particle resulting by metals friction, in its trajectory thought explosive atmosphere.
c) In the theoretical and experimental researches based on these two theories presented in the literature has not been found a classification on the ignition capacity of all industrial used metals, except for a generally based grouping which put the metals in two main groups:
   - Al, Mg, Ti – considered as the metal group having maximum ignition capacity;
   - Fe and Cu with their alloys – considered the alloy group with reduced ignition capacity.
d) With all this knowledge acquired on theoretic and experimental ways on the complex phenomena of explosive mixture ignition by mechanical sparks, there has not been found any pertinent explication for all metal range and especially for hardly oxidizing steels, which led to incompatible technical solutions from the explosion protection point of view. It is mentioned that, when different metals had been tested, by the authors, to generate mechanical sparks in the INSEMEX laboratories, the stainless steels induced ignitions on explosive atmospheres, proving a ignition ability which has to be taken into account when risk assessment are ran, in industry or at designing the equipment and protective systems intended for potentially explosive atmospheres.

3. ANALYSIS

The theoretic and experimental results obtained by the authors prove that besides the metals of the first group, stainless steels show, in certain situations, ignition capacity through mechanical sparks which are comparable with Al, Mg or Ti. Thus, in the explosion protection technique it had been arrived at applying non-adequate technical solutions (e.g. use of stainless steels in case of fans).

The ignition principle of the mechanical sparks is well-known; this is given by the ratio of the energy developed in the metallic incandescent particle and ignition energy of the combustible mixture. The ignition takes place when the caloric energy of the metallic particle reaches or exceeds the ignition energy of the combustible mixture.

In the specialty literature, to complete the ignition mechanism of the combustible mixtures with the mechanical sparks from very oxidizing metals it is used the curve d of the minimum ignition energy variation according to the amount of combustible gas, (determined having as ignition source an electric spark), as well as the variation curves of the caloric energy in the metallic particles [3] depending on the oxygen content in the combustible mixture a, b, c, presented together in figure 1.

In the inflammable mixture of air with combustible gas, increasing the combustible gas content results in a decreased oxygen amount. A lowered oxygen amount will result in a decreased temperature and caloric energy of the metallic particle, according to diagram a, b, c of the caloric energy by the mechanical sparks depending on the combustible gas content.

Determination of the optimum conditions of igniting the combustible mixture according to the combustible and oxygen concentration in the mixture, can be realized through examination of the curves corresponding to heat emission from mechanical sparks together with minimum ignition energy diagram depending on the fuel content.

Examining the curves shown in figure 1 points out that the caloric energy curve a corresponding to metallic particles having an initial temperature T_a intersects diagram d in two points. The points a' correspond to the poor concentration of fuel C_1, and the point a'' corresponds to the rich concentration of fuel C_3. In the zone limited by the points a', b', a'', the heat emission from sparks attains the value of the minimum ignition energy of the mixture and so the mixture is ignited.

In the case of formation of sparks having the lower initial temperature $T_b < T_a$, heat emission will be lesser (on the same mixture fuel-air). In the situation of an initial temperature T_b of the metallic particles detached, the heat emitted represented by the b curve, intersects the curve d in the point b', corresponding to the poor mixture concentration at a C_2 fuel concentration.

In the case of sparks with initial temperature $T_c < T_b$, the diagram of the heat amount does not intersect the d curve, and as a result, the sparks with the initial temperature $T_c < T_b$ emits an amount of heat insufficient to ignite the fuel-air mixture in any concentration.

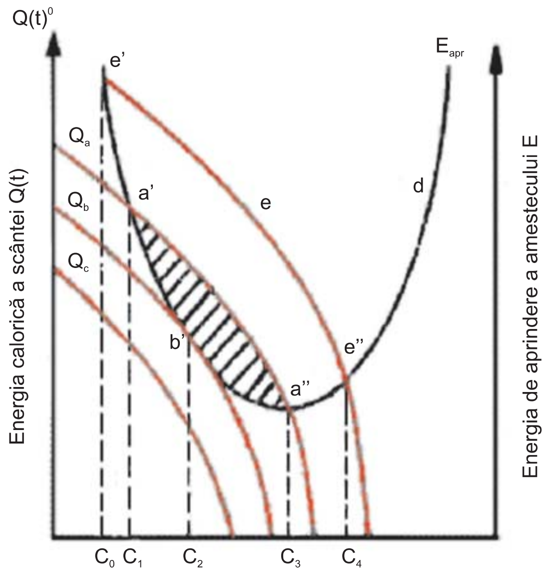
The a' and a'' points realize: a reduced range of concentrations (C_1 and C_3), within which the friction sparks can ignite the explosive mixture – respectively the explosive concentration limits possible by ignition by mechanical sparks from oxidisable metals. These limits of ignition by mechanical sparks represent a narrowing of range of concentration limits that are produced by the ignition sources which not depend by the oxygen amount, compared to the case of mechanical sparks resulted from hardly oxidizing metals (see figure 2). This reduction of the ignition range is produced generally because of the mixtures rich in fuel content that will determine, at their turn, a decreased content of oxygen, respectively a lowered temperature of the metallic particle.

The b' point corresponds to the optimal fuel concentration in air when ignited through mechanical sparks. Thus it can be concluded that the mechanical sparks by the intensive oxidizable metals can easily ignite a mixture poor in content. On the other hand, determining the point b' is important to find out the optimal concentration to ignite the fuel-air mixture, which represent the point of maximum sensitivity of the ignition, necessary in experimental research activity of laboratory tests in explosive atmosphere.

It is to be noticed that the maximum ignition sensitivity by mechanical sparks is found in a point differing from the one set when ignited by electrical sparks, which is given by the minimum of the curve d.

This mechanism for ignition the combustible mixture is valid for metals which maintain intensive processes of oxidization, ignition and burning the metallic particles.

To the metals which not oxidize intensive or hardly, as those classified as non--oxidizable, the metallic particle temperature depends on the initial friction temperature had at the moment of detaching in the mechanical process. In this case, the metallic particles have a temperature which does not depend on the oxygen quantity, respectively on the fuel from inflammable mixture.



Conținutul de gaz combustibil din amestec
$T_a > T_b > T_c$

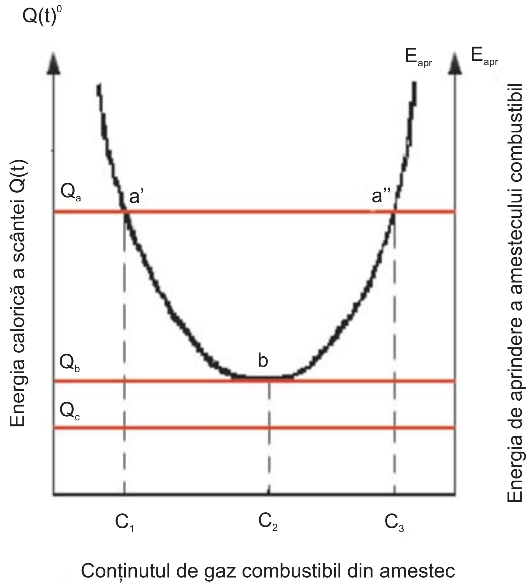
Figure 1. Determination of the optimal content for ignition of fuel mixture by mechanical sparks of oxidizable metals

The caloric energy of the metallic particles depends on: the temperature at the moment of being detached and the metal type. In figure 2 are presented the ignition energy diagram of the flammable gas mixture and the lines representing the caloric energy of the metallic particles which have constant values related to the combustible mixture concentrations. Ignition of the inflammable gas mixture from to mechanical sparks created by the hardly oxidizable metals can be analyzed through intersection of the ignition energy line by the inflammable gas mixture depending to the combustible quantity with caloric energy line of the mechanic particles.

In the case of the metallic particles detached with high temperature, which can be in some cases even the fusion temperature, when the particle is luminescent, the caloric energy of the particle Q_a can ignite the explosive mixture in the combustible concentration range C_1-C_3. This ignition range is two times higher than in the case of the oxidizable metallic particles.

Depending on the initial temperature, the mass or the particle volume and the metal type, the caloric energy by the metallic particle can achieve the diagram E_{apr}. in the limit b point. But the b represents the minimum ignition energy of the inflammable mixture agreed through ignition determination in laboratory having ignition source the electrical spark.

So, in the case of inoxidizable metallic particles, the minimum ignition energy of the inflammable mixture coincides with the minimum ignition energy determinate with electrical sparks.



$T_a > T_b > T_c$;

$Q_a > Q_b > Q_c$

Figure 2. Determination of the optimal content for ignition of combustible mixture by hardly oxidizable mechanical sparks

In the case of metallic particle which is detached with small temperature respective with small caloric energy, the line the caloric energy Q_c does not intersect the curve of ignition energy of the flammable mixture and in this case ignition does not occur. The mechanical sparks in this case are considered "cold mechanical sparks".

4. SOLUTIONS FOR EXPLOSION PROTECTION

The solutions for protection against explosions are based on two main criteria:

a) choosing the metals with a low ignition capacity;
b) adopting spark-proof protective coverings.

When conceiving and designing of the technical equipment intended for use in potential explosive atmospheres in the industrial areas or in firedamp mines, designers must to have in view many criteria for choosing of the metals materials.

A special case is represented by the equipment which requires often handling, mounting and dismantling, when the design requirement is to lower the weight. In this case, use of aluminum is most of the times the basic solution. The solution to prevent ignition hazard from mechanical sparks consist in the non-sparking protective covering. An example of application of this solution is the individual hydraulic light prop made from aluminum, for powered roof supports in firedamp coal mines.

Another special case is represented by the explosion-proof designed fans for potential explosive atmosphere with acetylene. At this equipment the danger of acetylides forming at contact between acetylene and different metals determined usage of aluminum alloys in manufacturing of rotor-stator items, but the final technical solution consisted in a protective covering made from inorganic corrosion protected materials.

5. CONCLUSIONS

The results of the fundamental research obtained are in accordance with the results known up to present in the specialty literature, which are completed through them; this confirms as principle, the generality of employing the caloric criterium for the whole range of metals. The ability to ignite by mechanically generated sparks of the metals of industrial use shows a great importance both under theoretical and practical aspects in the technique of explosion protection of the technical equipment an industrial plants employed in potentially explosive atmospheres in the firedamp mines or industrial sectors other than the mining ones.

Classification of metals in groups according to their ignition ability through mechanical sparks makes a database for the design, conceiving and manufacturing activities within the explosion protection against the danger of mechanically generated sparks in industrial environments with potentially explosive atmospheres.

The technical solutions of explosion protection identified by research require technological development so as, through decreasing the costs in the intermediate products, they can be enrolled in the market economy challenges.

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