SPECIFIC REQUIREMENTS FOR SELECTING PROTECTIVE SYSTEMS FOR TECHNOLOGICAL INSTALLATIONS WITH COMBUSTIBLE DUST

ADRIAN JURCA[1], DAN GABOR[2], MIRELA RADU[3]

Abstract: Industrial explosions have been a risk for as long as man has been processing, storing and transporting combustible dusts. The list of products that may combust in powdered form is extensive and includes a wide range of materials. Fine dust, such as wood, textiles, plastics, coal, carbon, light metals such as aluminium, magnesium, and titanium, agricultural products such as flour, cacao, sugar, grain, tobacco, and spices, as well as chemicals, pharmaceuticals, rubber, etc., may be explosive. Combustible dust occurs in a variety of industries and is a risk factor in many workplaces if not handled properly. In many cases, explosive atmosphere accumulation and ignition sources are not possible to be avoided, situation when an explosion might occur, if the combustible dust is present in suspension, mixed with air (with enough oxygen), within the explosion limits, together with an ignition source. Managing the explosion risk involve hazard identification, followed by explosion prevention and protection techniques. The paper presents a series of specific requirements regarding the principle of design and selection of protective systems used in technological installations with combustible dust in order to immediately stop the propagation of an incipient explosion and/or to limit the effective range of an explosion.

Keywords: combustible dust, explosion propagation, combustion characteristics, protective systems

1. INTRODUCTION

Many technological processes involving combustible dusts, suspended or accumulated, have the potential to lead to fire, explosion or decomposition in the presence of oxygen and an ignition source. The risk of dust explosions increases as more and more products take the form of powders or require the use of powders during

[1] *Ph.D. Eng., National Institute for Research and Development in Mine Safety and Protection to Explosion – INSEMEX Petroșani, adrian.jurca@insemex.ro*
[2] *Ph.D. Eng., INSEMEX Petroșani*
[3] *Ph.D. Eng., INSEMEX Petroșani*

manufacture. The list of products that may combust in powdered form is extensive and includes a wide range of materials. Fine dust, such as wood, textiles, plastics, coal, carbon, light metals such as aluminium, magnesium, and titanium, agricultural products such as flour, cacao, sugar, grain, tobacco, and spices, as well as chemicals, pharmaceuticals, rubber, etc., may be explosive. Combustible dust occurs in a variety of industries and is a risk factor in many workplaces if not handled properly.

Many are secondary explosions initiated by ignition of a flammable vapour cloud in the vicinity. The initial explosion may ignite further dusts and powders that have accumulated on level surfaces. The damage caused by dust explosions is generally worse than that caused from vapour phase explosions.

This emphasises the need for proper housekeeping to ensure that these incidents are not escalated. A dust explosion can only occur if there is a flammable atmosphere (an explosive dust mixed with air/oxidant) and an ignition source. The conditions required to ignite dust clouds are dependent on several factors:

- the dust must be combustible. Solids are grouped in three classifications;
- the dust must have a particle size distribution that will allow the propagation of flame;
- the dispersed cloud or suspension must have sufficient oxidant to support combustion;
- the dust cloud must be within the explosible range;
- sufficient ignition energy must be in contact with the dust cloud in order to ignite it.

The five elements outlined are required to initiate a dust explosion. Unlike the fire triangle, a dust explosion requires two additional elements in the form of dispersion of dust particles in the right concentration and confinement of the dust cloud itself. Dispersed airborne dust burns more rapidly and confinement allows for pressure build up. With the additional two elements in place, all five are aligned, increasing the likelihood of an explosion – figure 1 [1].

Fig.1. Explosion pentagon

The requirement to ensure safe handling and processing of powders and dusts relies on the operational effectiveness of employees, equipment and protective systems to ensure that at least two of the above conditions are removed during operation. The probability of a dust explosion during processing is related to the properties of materials, such as the minimum ignition energy, K_{st} value, etc. together with the nature of the operation being performed and the equipment used. One can therefore specify the level of safety required for any powder – operation combination.

The most important combustion characteristics for combustible dusts are, according to the series of standards SR EN 14034-1,2,3: Determination of explosion characteristics of powder clouds, [2, 3, 4]:

a) maximum explosion pressure P_{ex} is the highest overpressure that occurs during an explosion of a powder mixture in a closed vessel;

b) maximum pressure rise rate $(dP / dt)_{max}$ is the maximum value of the pressure increase per unit time during explosions, for all explosive atmospheres in the explosive range of combustible substances in a closed vessel under the specified test conditions and atmospheric conditions standard;

c) explosion index for combustible dusts - K_{max}, K_{st} volume independent characteristic that is calculated using the cubic equation:

$$(dP / dt)_{max} \times \sqrt[3]{V} = \text{const.} = K_{st} = K_{max} \tag{1}$$

where V represents the volume of the test vessel.

d) minimum explosion concentration or lower explosion limit (CmEx, LIE or LEL) - lowest concentration of a combustible dust in mixture with air at which an explosion occurs.

These parameters vary considerably depending on the dust type and particle size distribution, their knowledge being a first step for carrying out a proper explosion risk assessment in installations which circulate combustible dusts. Knowing the explosion characteristics for combustible dusts resulting from a technological process or which are conveyed within an installation, the adequate protection systems can be designed and selected so that the level of safety within the installations is high [5, 6].

The explosion and combustion characteristics of powders have to be known, in order to develop and adopt adequate preventive and protective safety measures [7, 8].

2. METHODOLOGY FOR FUNCTIONAL SAFETY ASSESSMENT OF PROTECTIVE SYSTEMS

Integrated explosion safety is conceived to prevent the formation of explosive atmospheres as well as sources of ignition and, should an explosion nevertheless occur, to halt it immediately and/or to limit its effects. In this connection protective systems must be designed and constructed after due analysis of possible operating faults that limit or prevent the capacity of the system to stop an explosion.

Therefore, it is absolutely necessary to conduct a functional safety assessment process. Functional safety assessment is a series of logical steps (see Figure 2) that enable designers and safety engineers to examine in a systematic way the function of a protective system or a part of it.

The objective shall be to achieve an adequate level of functionality and reliability according to the state of the art and technical and economic requirements at the time of construction.

This assessment includes the following four steps: description of the protective system, identification of failures, functional safety estimation with functionality and reliability and functional safety evaluation.

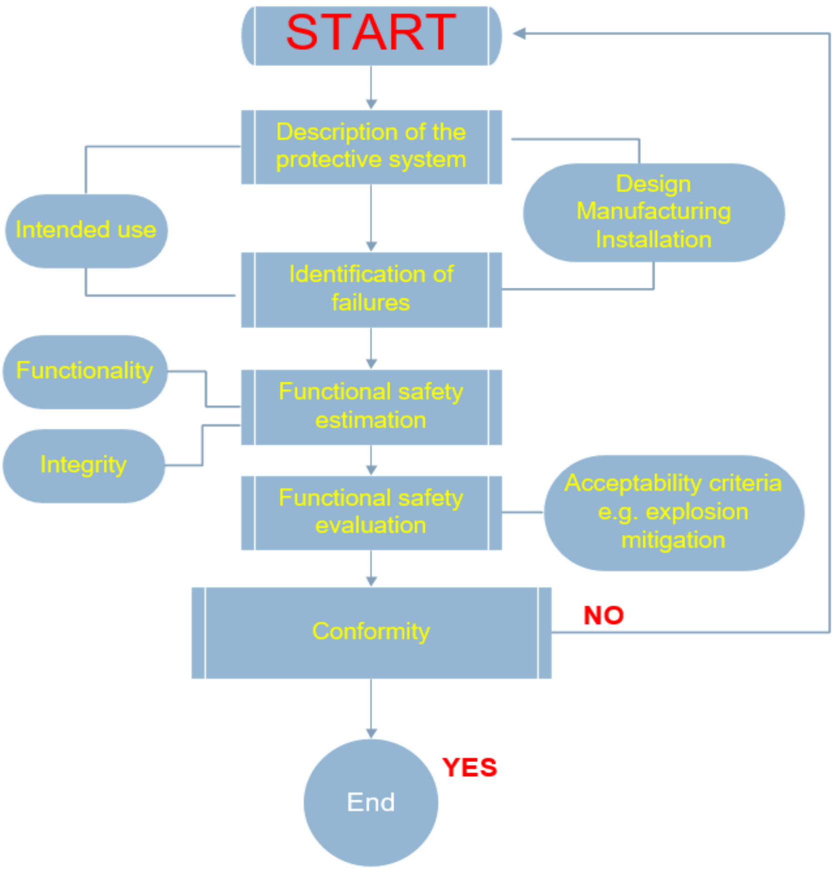

Fig. 2. Functional safety assessment for design of protective systems

The phased approach is achieved by understanding the function of the protection system and the types of explosions. In this first step, a functional and condition analysis of the intended use is undertaken.

The intended use shall consider the following essential elements: description of the type of explosions - explosion index for combustible dusts K_{st} – table 1, process conditions, limits in terms of use, time, space, accurate definition of the function, selection of materials for construction, performance, lifetime and configuration.

Table 1. **Explosion index for combustible dusts**

Dust explosion index	K_{st} **[bar·m·s⁻¹]**	**Characteristic**
St 0	0	No explosion
St 1	> 0 ÷ 200	Weak explosion
St 2	> 200 ÷ 300	Strong explosion
St 3	> 300	Very strong explosion

Generally, in the second step, a protective system shall be assessed by potential sources of failure of the protective system. Protective systems are distinguished in the following way: passive systems (e.g. flame arrester, venting system) and active systems (e.g. suppression system).

After the failure identification the functional safety of the protective system has to be estimated by determining the probability of occurrence of the faults violating the required performance of the protective system in terms of its function and integrity. The ability to perform the required function can be partly quantified by reliability figures and/or expression of the fault tolerance of the system structure. The probability shall be estimated and evaluated for each of the identified parameters that can lead to a failure of the protective function of the system for the function and integrity requirements. The probability estimate can be done qualitatively, semi-quantitative or quantitative depending on the criticality of the protective system in reducing the probability of failure and/or the complexity of the system and the safety related devices.

Protective devices included in the protective systems should have an ATEX certificate confirming their admission to operation as protective devices and an ATEX certificate or the manufacturer's declaration confirming their admission to operation in the respective explosion risk zone.

3. SELECTION OF THE ADEQUATE EXPLOSION PROTECTION SOLUTION

Selecting the proper explosion protection solution involves a detailed analysis of the specific risks, the environment, and the requirements of the facility. Here are the key steps and considerations for choosing the appropriate passive and active explosion protection solution. Protective systems should be selected while taking into account the parameters of the protected device/plant and the explosive atmosphere.

The basic parameters that should be taken into account are: the volume and shape of the protected device, explosion index K_{st}, maximum explosion pressure P_{max}, structural strength of the device as expressed by the maximum pressure to which the device is resistant and the location within the technological plant.

There are four basic systems types employed for explosion protection: venting, flameless venting, isolation and suppression. The flow chart below shows the process to select the most appropriate system(s) to specifically fit for an application – figure 3.

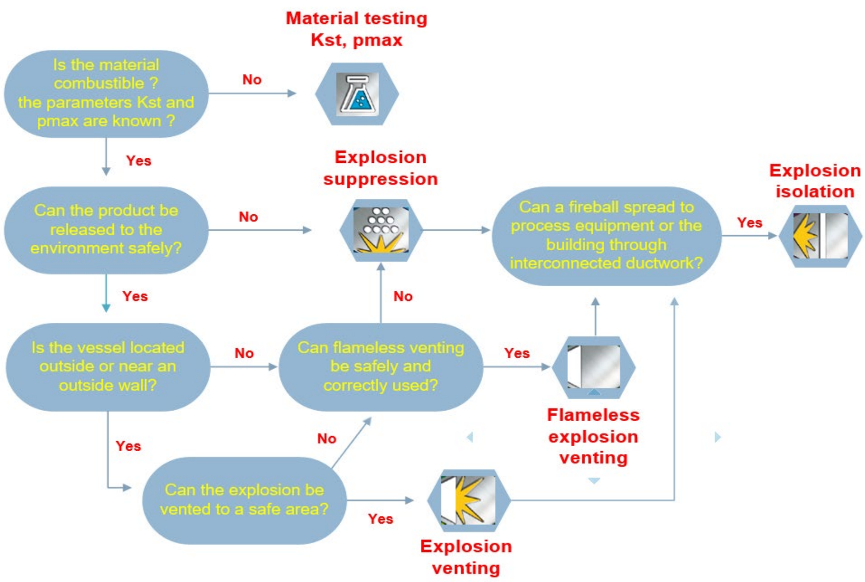

Fig. 3. Chart of explosion protection technique

Knowing the explosion characteristics of combustible dusts resulting from a technological process or that are conveyed within an installation is the first step in designing and choosing adequate protection systems so that the level of safety within the installations is high.

4. CONCLUSIONS

Protective systems in the context of explosions are designed to prevent explosions, mitigate their effects, and protect people, property, and the environment. These systems can be classified into two main categories: passive protective systems (e.g. flame arrester, venting system) and active protective systems (e.g. suppression system).

Passive protective systems for dust explosions are designed to mitigate the impact of an explosion without requiring active intervention or external power. These systems typically focus on containing the explosion, relieving pressure, and preventing the spread of the explosion to other areas.

Active protective systems for dust explosions are designed to detect and suppress explosions in their incipient stages, prevent their spread, and minimize the damage caused by such events. These systems typically require sensors, control units, and actuators to function effectively.

Determination the explosion characteristics for combustible dust has an important role in the first phase of the explosion risk assessment, and in design and selection phase of the protective systems intended for use in potentially explosive atmosphere generated by de combustible dusts.

The diagram illustrates the sequential process for choosing technical solutions for explosion protection. These solutions include active and passive protective systems like explosion isolation, explosion venting, flameless explosion venting, and explosion suppression. The selection of these protective systems depends on the specific technological processes encountered in practical situations. The diagram is an important instrument for individuals who choose and implement protective systems in technological installations where explosive atmospheres generated by combustible dusts are present.

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