Aspects of explosion risk assessment in the case of bucket elevators

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Abstract. Many of the technological processes that take place in the installations in which cereal products are transported and / or stored, involve the existence of combustible dusts. These dusts may be suspended in the air, or in the form of accumulations in layers or deposits of dust of various thicknesses, and may lead to fires, explosions or catalytic decomposition in the presence of oxygen.
If the combustible dusts are swirling in the air in appropriate proportions and an effective source of ignition is present, they can burn rapidly and with considerable explosive force.
Given that most of the time, as a result of an explosion of combustible dust, the resulting damage is generally greater than that caused by an explosion of flammable gases, it is necessary to pay special attention to the way in which they are taken. and implemented measures to protect and prevent explosions of combustible dust.
This paper highlights the principles and main factors that must be taken into account when conducting an explosion risk assessment for a bucket elevator carrying grain products, in order to establish and implement the necessary prevention and protection measures to ensure a minimum level. acceptable risk.

1 Introduction

The industrial process of vertical transport of cereal products in a grain warehouse, for the loading of vertical silos on site, is carried out by means of bucket elevators. The development of this technological process leads to the appearance of combustible dusts, which are either in suspension or deposited in layers or dust deposits, there is a danger of fire, explosion or decomposition in the presence of oxygen.

The occurrence of a fire or explosion in such a transport facility, which carries combustible dusts, can have devastating effects through material damage, disruption of technological flow and production, or even damage to the bodily integrity of the personnel serving that installation.

Therefore, in the case of a bucket elevator, due to the possibility of the formation of potentially explosive atmospheres generated by the fuel / air mixture, the danger of

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explosion must be considered as a major danger, which requires the adoption of appropriate protection measures to ensure the prevention and explosion protection, measures that can only be adopted and implemented following an assessment of the existing risk of explosion.

It should be borne in mind that the explosion hazard in the case of a bucket elevator is related not only to the dusty material being transported but also to the existing protection systems and components, as well as to the materials used for the manufacture of the elevator itself and its components.

An explosive atmosphere of combustible dust is defined as a mixture of combustible dust air, dust or cloth, a mixture in which, after ignition, combustion is transmitted to the entire unburned mixture. [1]

In the case of explosive air / dust atmospheres, an explosion occurs only if the concentration of combustible dust suspended in a mixture with air is within the explosive range of that dust, respectively between the lower explosive limit (LFL) and the upper explosive limit (UFL), and at the same time a source of ignition is present whose initiation energy is high enough to initiate the former air / dust mixture.

Therefore, the dust explosion occurs only if there is a simultaneous interaction of the combustible dust with the oxidant and the ignition source, taking into account at the same time the aspects related to the closure of the mixture, thus resulting in the so-called pentagon explosion, shown in Figure 1. [2, 3].

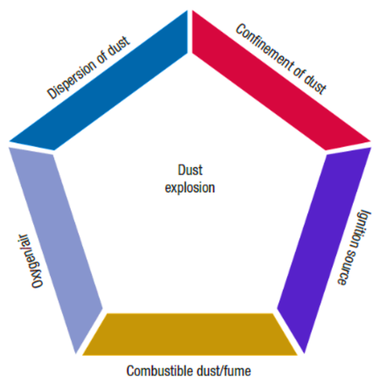

Fig.1. – Pentagon of explosion

The manner in which a dust explosion occurs, related to its dynamics and violence, depends on a number of factors, the most important of which are given below:

✓ Chemical composition of combustible dust – any combustible dust is characterized by the so-called explosion index. This explosion index is in fact the specific constant of the respective fuel dust, is denoted by k_{st}, and indicates the measure of the explosive value of the fuel dust in question. Depending on this explosion index, the fuel dust can be classified in one of the four explosion classes, as can be seen in table no. 1.

Table 1. Classification of combustible dusts according to k_{st}.

Dust Explosion Class	K_{st} [bar×m/s]	Characteristic
St 0	0	No explosion
St 1	>0 ÷200	Weak explosion
St 2	>200 ÷ 300	Strong explosion
St 3	>300	Very strong explosion

✓ Concentration of air / fuel dust mixture – combustible dusts form potentially explosive atmospheres only at concentrations in the explosive range. Although a cloud of dust with a very high concentration (concentration above the upper limit of explosiveness) may not be explosive, there is still the danger that, if the concentration decreases, we will enter the field of explosiveness. In general, in the case of combustible dusts, the lower limit of explosiveness is between 20 g/m^3 and 60 g/m^3, while the upper limit of explosiveness is between 2 kg/m^3 and 6 kg/m^3.

✓ The size of the dust particles – the severity of a dust explosion depends very much on this factor, because the finer the dust particles, the longer they remain suspended in the air for a longer period of time, and the more likely a potentially explosive atmosphere is present.

✓ Homogeneity of dust clouds, presence of vapours, gases or inert gases, aspects related to atmospheric turbulence, moisture content of particles, etc.

✓ The way in which cleanliness is maintained in areas where combustible dusts are present. In the absence of a systematic cleaning plan, dust particles suspended in the air are deposited on surfaces, resulting in layers or deposits of dust of various thicknesses, which, in the event of an explosion, can be swirled, thus ensuring fuel needed for other secondary explosions.

2 Presentation of bucket elevators

Bucket elevators are technical equipment consisting of three main parts: the elevator bucket base, the elevator bucket leg or legs and the elevator head, through which bulk materials are handled. This equipment carries materials in powder form or as coarse products (such as cereal products, wood chips, etc.) in a vertical plane, through a continuous movement of the supplied cups, ensuring a transport speed of between 1 m/s and 4 m/s.

Cups are open containers of different sizes, made of mild steel, stainless steel or plastic, fixed on a flexible continuous strip or on chains, which ensure their vertical movement.

Bucket elevators are equipment used mainly for transporting grain in their storage silos. The specific technological process includes the unloading of the grain to be stored in silos, in the receiving funnel located at the base of the elevator. From here, the grain is picked up by means of elevator buckets and transported vertically to the desired height. The grain is unloaded from the cups into the silo, through its unloading mouth under the elevator head.

Depending on the required production capacity and the type of product to be transported, the traction elements of the elevator (buckets, belt, electric drive motor) are dimensioned and the operating parameters are selected (transport speed).

The support of the bucket elevator is made by means of a support system that can have different constructive solutions:

- Metal tower composed of laminated profiles and resistance metal structure;
- Connection system that is anchored to the silo, if the elevator is mounted near it;
- Anchoring cable system through which the silo is fixed to the ground.

In principle, a bucket elevator comprises the following assembly components, shown in Figure 2. [4]

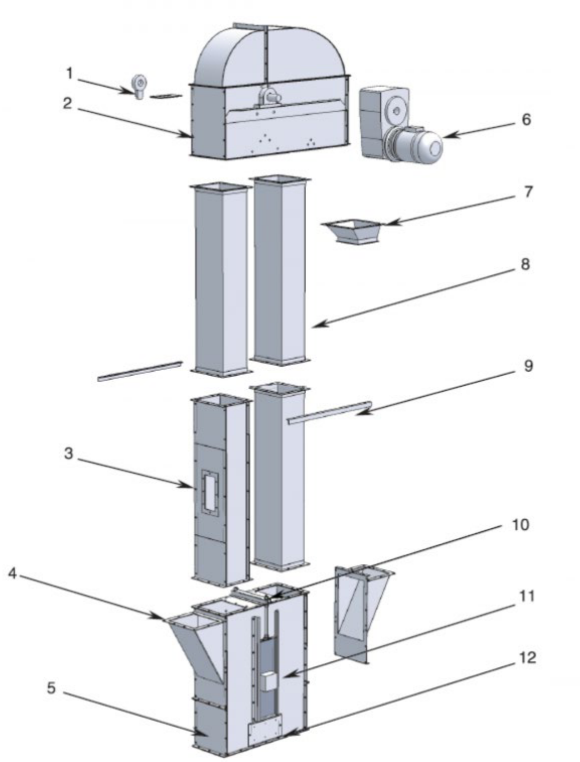

Fig.2. – Bucket elevator - components

where:

1. anti-return system	5. elevator leg	9. solidarity bar
2. elevator head	6. gear motors	10. stretching shaft
3. inspection window	7. exhaust funnel	11. extension shaft protection system
4. product loading funnel	8. elevator body	12. access mouth for cleaning

2.1 Classification of bucket elevators

Depending on the nature of the technological process and the process requirements, bucket elevators can be classified according to the following criteria:

a. depending on the direction of transport:
   - elevators that transport material on an inclined plane;
   - elevators that transport material vertically.
b. depending on how they are used:
   - elevators located at a fixed point (stationary),
   - movable elevators.
c. depending on the traction device:
   - elevators with flexible continuous belt;
   - chain elevators.
d. d. depending on the transport speed:
   - fast elevators - transports the material with a speed higher than 1 m / s;
   - slow elevators - transports the material with a speed of less than 1 m / s.
e. depending on how the transported material is unloaded:
   - centrifugal unloading elevators - found in fast elevators;

- gravity unloading elevators - found in slow elevators;
- elevators with centrifugal-gravity discharge.

2.2 Types of bucket elevators

The industrial processes of transporting cereal products vertically are carried out by using bucket elevators in different variants and construction types. If we refer to the way the bucket elevator housing looks, we find double-legged, single-legged and Z-type elevators.

2.2.1 Two-legged bucket elevator

This type of elevator is characterized by the fact that the base and the head are interconnected by means of two legs. One leg, called the leg up, houses the band and cups full of grain moving toward the head, and the second leg, also called the foot down, houses the band and empty cups that return to the base. Overall, such a bucket elevator is shown in Figure 3.

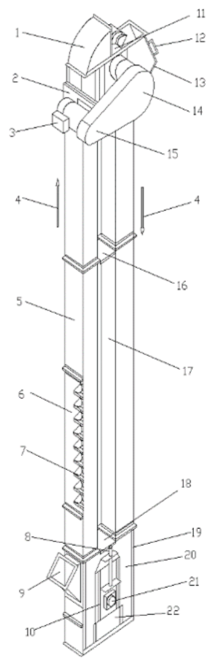

Fig.3. – Two-legged bucket elevator - components

where:

1. curved head housing	9. angular entrance	17. pressed steel leg
2. pressed steel engine mounts	10. pulley made of steel	18. upper access cover of the boot
3. electric drive motor	11. steel head pulley	19. rear entrance
4. direction of travel	12. head access panel	20. pressed steel housing
5. removable cover for inspection	13. angular or vertical output	21. flange bearings and caps
6. pressed steel cups	14. speed reducer for shaft mounting	22. trunk side access cover
7. reinforced synthetic rubber strap	15. fully closed drive belt system	
8. belt tensioner	16. foot joint platei	

2.2.2 One-legged bucket elevator

This type of elevator is characterized by the fact that the base and the head are interconnected by means of a single leg inside which are found both the ascending branch of the belt with full cups and the descending branch of the belt with empty cups. Overall, such a bucket elevator is shown in Figure 4.

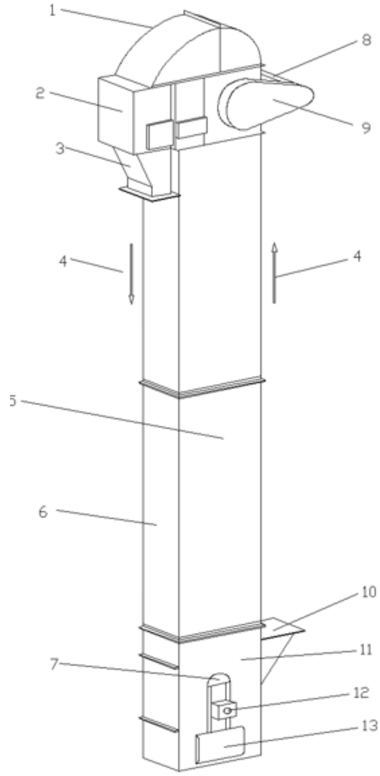

Fig.4. – Single leg bucket elevator - components

where:

1. curved head housing	6. removable cover for inspection	11. pressed steel boot (base)
2. head access panel	7. belt tensioner	12. bearings and flange caps
3. angular or vertical output	8. electric drive motor	13. trunk side access cover
4. direction of travel	9. fully closed drive belt system	
5. pressed steel leg	10. angular entrance	

2.2.3 Z-cup elevator

What is characteristic of such a type of bucket and chain elevator is that it operates at low transport speeds and is not used for transporting fuel dust. Due to this, it generates low dust, and implicitly, the risk of ignition is reduced. Figure 5 shows a cross section through such an elevator.

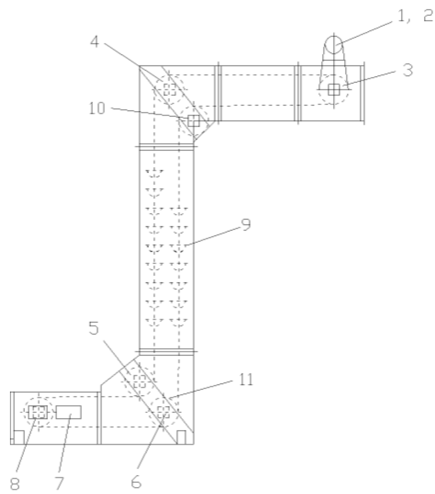

Fig.5. – Z-type bucket elevator - components

where:

1. gear motors
2. drive chain
3. flange bearings
4. non-return bearing
5. flange bearing
6. pickup bearing
7. chain tensioner
8. flange bearing
9. cup
10. flange bearing
11. pinion

3 Explosion risk assessment of bucket elevators intended for the transport of grain

3.1 General concepts

Explosion risk assessment for a bucket elevator carrying grain must be performed by both the equipment manufacturer, in order to fulfil the obligations regarding the conformity of the product with the requirements of the ATEx Directive [5], and by the third-party assessors involved in the evaluation process of that product.

In principle, the actions to be performed by the bucket elevator manufacturer are:

- to make the risk assessment, by applying the requirements provided in the standard SR EN 1127-1: 2019 [1];
- to define the requirements of the bucket elevator to be operated in a potentially explosive atmosphere, as well as the safety and control devices, even if they are not located in the explosive atmosphere, but which contribute to the proper functioning of the bucket elevator;
- to present, if deemed necessary, all additional protection measures to be taken and implemented following the conclusions of the explosion risk assessment carried out;
- to produce a range of bucket elevators with the same requirements, intended for use under the conditions defined during the risk analysis and in accordance with Directive 2014/34/EU [5].

Manufacturers of bucket elevators, in order to comply with the requirements, set out in Annex 2 of the ATEx Directive [5], regarding explosion hazards, must adopt and implement all the measures at their disposal for:

- to prevent the occurrence of potentially explosive dust / air atmospheres that can be produced by technical equipment and protective systems;
- to prevent the ignition of explosive atmospheres, by analysing the cause of production of each source of initiation (electric or non-electric);
- stop or limit the flame and explosion pressure to a level of safety sufficient not to affect the persons involved in the production process and the environment.

For a correct explosion risk assessment, it is necessary to start from the principles underlying explosion prevention and protection. So:

- prevention is the concept that is based on avoiding the occurrence of potentially explosive atmospheres and / or avoiding efficient ignition sources, by eliminating or detecting them;
- explosion protection is based on the application of explosion suppression or isolation ventilation rules, specially adapted for bucket elevators. These specific rules may be based on agreed testing methods

The process of evaluating the risk of explosion in bucket elevators requires special attention, as this equipment have, over time, been involved in many dust explosions, having, by construction, many potential sources of ignition. The most common sources of potentially explosive atmospheres are the result of mechanical problems, such as friction between the belt and the housing, heating of the rotating mechanical parts on the elevator head and the funnel, impact between damaged cups or between cups and foreign objects. These mechanical problems can lead to explosive atmospheres: impact or vibration will cause dust to form and create an explosive atmosphere. Therefore, even if there is no explosive mixture of air-dust inside a bucket elevator during normal operation, however, mechanical problems can lead to an explosive atmosphere and then to an explosion.

Also, the danger of explosion in bucket elevators is greatly influenced by the nature and appearance of the grain to be transported. In this case, the fine fraction of cereals plays a decisive role, with particle sizes smaller than 500 μm and how easily a cloud of dust forms. Always, if the grain contains some dust, there must be a risk of explosion.

3.2 Explosion risk assessment

The probability of an air / dust explosion in the case of a bucket elevator carrying grain is given by the probability of the occurrence of potentially explosive atmospheres, the presence of ignition sources and the actual ignition of the explosive atmosphere. The bucket elevator location and the existence of adequate protection systems will also determine the consequences of an explosion.

The adoption and implementation of explosion prevention and / or protection measures depends on the case and should be based on the answers to the following questions: **is the ignition probable or not, the effects can be tolerated or not, the risks are acceptable or not?**

The user of the bucket elevator normally chooses it according to the category of equipment and will then perform a risk analysis and assessment depending on the local circumstances and the nature of the technological process. Such an analysis must also take into account the likelihood that the sources of ignition from the outside will penetrate inside the bucket elevator. Depending on the acceptability of the risks, in addition to preventive measures (based on the category of bucket elevator) it may be necessary to adopt explosion protection measures.

In principle, the explosion hazard analysis for a bucket elevator intended for transporting grain can be performed based on the logic diagram shown in Figure 6.

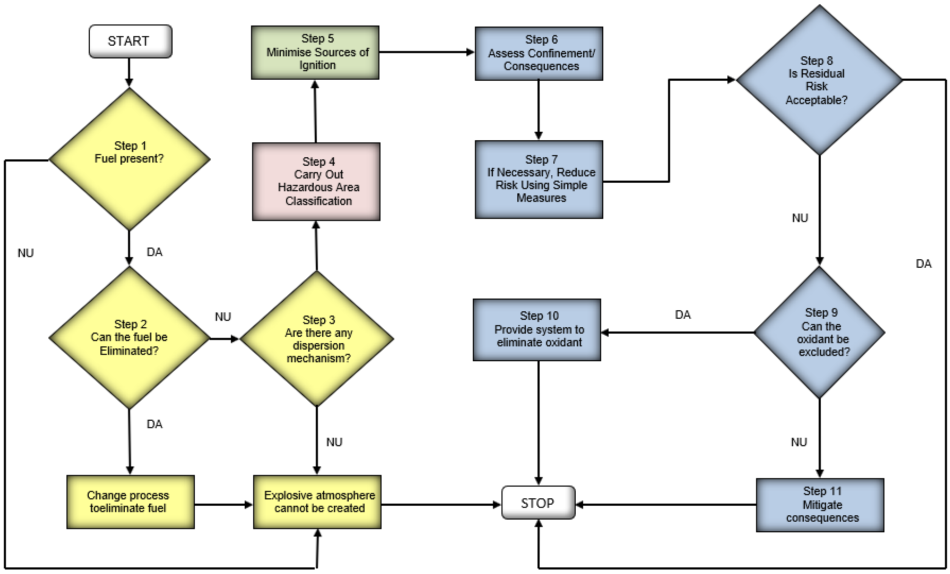

Fig. 6. The explosion risk logic diagram

As can be seen, in the presence of combustible dust, after the classification of hazardous areas in step 4 has been carried out, it is first necessary to identify all sources of ignition and to check whether the protective measures adopted and implemented prevent the occurrence efficient ignition sources.

In relation to equipment, the identification of potential sources of ignition capable of igniting an explosive atmosphere and of effective sources of ignition, depending on the frequency of occurrence, must be performed by the equipment manufacturer in accordance with SR EN ISO 80079-36 [6]. The list of possible ignition sources is indicated in SR EN 1127-1 [1].

There are also sources of ignition related to other issues that should be considered by the end user of the bucket elevator, namely:

- ignition sources introduced from the connected equipment. Typical examples are hot, incandescent products, embers and / or explosions that may occur in the connected equipment;
- external ignition sources due to smoking, maintenance, welding, cutting, etc. These should be prevented by organizational measures;
- sources of ignition that may arise from the transported product itself: e.g., by self-heating in warehouses and which during transport reach the inside of the bucket elevator.

It should be noted that the ignition sources can also be created by the bucket elevator as a whole, mainly due to the presence of electrical equipment, belt drive systems and bearings. If the bucket elevator is to be used in a potentially explosive atmosphere, its manufacturer must also consider these sources of ignition and comply with the requirements of the SR EN 80079 series for non-electrical equipment and SR EN 60079 for electrical equipment.

Therefore, in the case of bucket elevators carrying grain, the following sources of initiation can be identified:

- potential sources of ignition due to the equipment that is part of the bucket elevator - shown in table 2

Table 2. Equipment ignition sources [7]

Potential ignition sources	Possible causes
Hot surfaces	• Friction between the belt on which the buckets are fixed to the wall of the lift housing due to misalignment of the belt • Friction between the bucket elevator belt and the drive drum due to slipping of the belt • Rubbing loose parts of the bucket elevator (loose bucket, lost pulley parts, etc.) with moving parts • Damage to bearings and gears
Mechanical sparks	• Mechanical sparks due to cups colliding with the housing wall (due to insufficient belt tension, defective belt, loose cups) or with the discharge chute • Non-alignment of the drive wheel
Electrical equipment	• Electrical equipment and motors • Improper grounding and / or equipotential bonding
Electrostatic discharge	• Electrostatic charging due to the separation processes that appear between the belts and the drive wheels • Electrostatic charging of cups due to electrostatic induction • Electrostatic charging of any other installed conductive component that is not grounded

- potential ignition sources introduced or coming from outside the elevator - shown in Table 3

Table 3. Ignition sources introduced or acting from the outside [7]

Potential ignition sources	Possible causes
Hot surfaces	• Introduction of foreign material • Introduction of incandescent particles • Welding, grinding, cutting operations • Damage to the housing due to external mechanical action
Hot flames and gases, including hot particles	• Introduction of incandescent particles • Propagation of fire or explosion from connected or external installations
Mechanical sparks	• Introduction of foreign material • Damage to the housing due to external mechanical action
Lightning	• Inadequate lightning protection

- potential sources of ignition from the product itself - these occur when self-ignition or exothermic decomposition is expected to be possible, taking into account the characteristics of the cereals.

4 Conclusions

The use of bucket elevators and the protection systems with which they are provided in technological processes involving the transport and storage of cereal products in grain warehouses and feed mills may lead to potentially explosive air / dust atmospheres, and, in the presence of efficient ignition sources, in the event of explosions. Therefore, in order to protect the workers involved in the production process, the assessment of the risk of explosion in this case is of particular importance.

The explosion risk assessment, in accordance with the requirements of the legislation in force, as well as the adoption of protection measures, where necessary, in order to ensure an acceptable level of safety, must be carried out by both bucket elevator manufacturers and who use this equipment.

In order to perform the explosion risk assessment, all electrical and non-electrical equipment that is part of a bucket elevator operating in environments where it is possible to form explosive air / dust atmospheres must be subjected to a risk analysis, with identification and analysis of all potential sources of ignition.

The necessary safeguards must also be laid down to be adopted and implemented to prevent potential sources of ignition from becoming effective.

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