Fire and Explosion Hazard Aspects for Bucket Elevators

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Abstract. Technological installations for the vertical transport of cereal products, are affected by the presence of combustible dusts that can be mixed with air, in suspension, or in the form of dust layers of different thicknesses. The presence of these combustible dusts is a constant danger of fires or even explosions. In combustible dusts are swirled in the air in concentrations in their explosive range and there is also an ignition source, the dusts can burn quickly and even give rise to explosions, in which case the force and pressure developed is considerable. Since, in most cases, following a fire and especially a combustible dust explosion, the damage caused is quantified by immeasurable material damage and even by recording human losses, special attention must be paid to how they are identified and implemented protection and prevention measures to prevent fires and combustible dust explosions. In this paper, the principles and main factors that must be considered when quantifying the risk of fire and/or explosion for a bucket elevator used for the vertical transport of cereal products are highlighted. A number of recommendations for the safe use of these lifts are also presented.

1 Introduction

The technological installations used for the vertical transport of cereal products are affected by the presence of combustible dusts resulting from these technological processes. These technological installations for the vertical transport of grain are mainly found in grain warehouses, being used to load the existing vertical silos on the site of the respective warehouses, and materialize in the form of bucket elevators.

In general, buckets elevators are made of three main parts: the base of the elevator, which includes the receiving funnel through which the elevator is fed with cereal products, the leg or legs of the elevator, inside of which there is the belt with buckets that ensures vertical transport of grain and the head of the elevator, where the drive group of the bucket belt is located.

In principle, a bucket elevator is composed of several components, shown in figure 1.

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The specific technological process for a bucket elevator includes the following phases:

✓ Feeding the elevator with grain through the receiving funnel located at its base;
✓ Taking the grain by the buckets of the elevator and transporting them vertically to the desired height;
✓ Unloading the grain from the buckets, either directly into the storage silo or on another transport facility (belt or scraper conveyor) that ensures the connection between the elevator and the grain storage silos.

Grain transport with bucket elevators is carried out at a transport speed between 1 m/s and 4 m/s and leads to the formation of combustible dusts. These dusts are present either in suspension, mixed with air, or deposited in layers or in dust deposits of different thicknesses, with the constant risk of fire and/or explosion, in the presence of an effective source of ignition.

The effects of a fire or an explosion in the case of a bucket elevator are, most of the time, devastating, being materialized by material destruction, disruption of the technological flow or even affecting the bodily integrity of the personnel serving the respective installation.

Due to these aspects, in the case of buckets elevator that ensure the transport of cereal products, the danger of a fire and/or an explosion must be considered, being a major danger, which requires the adoption of protective measures appropriate to each situation in part.
The occurrence of a fire and/or an explosion depends both on the materials and hazardous substances in the form of dust transported, as well as on the materials used to make the equipment, protection systems and components that make up the bucket elevator.

For a correct fire and/or explosion hazard assessment, in the case of bucket elevators it is necessary to start from the principles underlying both fire and explosion prevention and protection. In this sense, it can be said that prevention is based on avoiding the occurrence of a potentially explosive atmosphere and/or detecting and eliminating effective sources of ignition, and protection against explosion requires the application of specific rules for ventilation, suppression or isolation of the explosion, specially adapted for bucket elevators. These specific rules may be based on agreed test methods.

Analysis and evaluation of the danger of fires and/or explosions, in the case of bucket elevators, requires special attention, since these equipments have, from a constructive point of view, many potential sources of ignition. Most of the time, these potential sources of ignition appear as a result of mechanical problems, among which we mention: friction between the belt and the housing in case of misalignment of the belt, heating above the maximum allowed limit of mechanical parts in rotational motion, impact which can occur between damaged cups or between cups and foreign objects accidentally penetrated inside the elevator.

It should also be considered that the impact or vibrations resulting from mechanical problems will lead to dust deposits inside the elevator, at its base, potentially creating potentially explosive atmospheres in the event of swirling of the deposited dust.

Also, even if an ignition source does not produce an explosion, it can lead to a fire that can spread rapidly, as the foot of a bucket elevator behaves like a chimney under these conditions. On the other hand, the cups that make up the buckets elevator also influence the flame acceleration, as follows:

- if the cups are made of metal, the flame will be cooled and its acceleration will be reduced;
- if the cups are made of various plastic materials, they can become part of the fuel for the fire;
- the cups form repeated obstacles that lead to the appearance of increased turbulence, and therefore promote flame accelerations.

2 Explosion hazards

Explosive combustible dust atmosphere is defined as a mixture with air of combustible dust, powders or lint, a mixture in which, after ignition, combustion is carried throughout the unburned mixture. [2]

A combustible dust explosion occurs if the concentration of combustible dust suspended in air is within the explosive range of that dust, i.e. between the two explosive limits: the lower explosive limit (LFL) and the upper explosive limit (UFL), simultaneously with the presence of an ignition source whose initiation energy is high enough to ignite the air/dust mixture formed.

Therefore, the dust explosion occurs only if there is a simultaneous interaction of the combustible dust with the oxidizer and the ignition source, while considering the aspects related to the closure of the mixture, thus resulting in the so-called explosion pentagon, shown in figure 2.
In the case of a bucket elevator used for the vertical transport of various grain products, for an explosion to occur, the following conditions must be met simultaneously:

- combustible dust must be present either in layers or deposits, or swirled within its explosive limits;
- oxygen must be present in a sufficient concentration to sustain combustion;
- the existence of an effective source of ignition.

2.1 The presence of potentially explosive atmospheres

The possibility of a potentially explosive atmosphere is highly dependent on the grain product being handled and the operating conditions of the bucket elevator. Thus, depending on the average size of the products being handled, two distinct situations can be encountered:

**Situation A**

The bucket elevator transports a product that has an average particle size of less than 500 μm or a dusty product that includes a large amount of particles of less than 100 μm. Due to these aspects, in the case of normal operation of the elevator, dust clouds can frequently form inside it, the concentration of which is probably higher than the lower explosive limit, and we can assume that in this situation a potentially explosive atmosphere is present frequently.

This can include grains (such as wheat, barley, corn) that have not been cleaned and are quite dusty, as well as soybeans that are not cleaned well.

**Situation B**

By means of the bucket elevator, coarse cereal products with a particle size greater than 1000 μm are transported, with a very limited amount of microparticles in their composition. In this case we assume that a potentially explosive atmosphere is likely to occur only occasionally during normal operation.

In this situation we can fit cereals and soybeans, if they have undergone a thorough cleaning process, as well as sunflower seeds, because their hulls are quite fat and do not lead to the appearance of dust.

With regard to the appearance of potentially explosive atmospheres, the conditions of the technological process and the specific characteristics of the transported cereal product have a particular influence, namely: moisture content, particle size, friability, flow characteristics and impurities.

In both situation A and B, existing dust can adhere to the inner surfaces of the bucket elevator, forming dust deposits that can be dispersed by vibration and other mechanical movements, resulting in potentially explosive atmospheres, which for which the respective areas will be classified from an Ex point of view as area 20 or 21.

Only under particular conditions, in the case of specific applications, where there is clear evidence that hazardous dust deposits cannot be created, could the Ex classification of the area concerned as zone 22 be considered.
It should also be considered that inside a bucket elevator that transports cereal products, due to the friction of the cereal grains, there is always the possibility of dust formation.

### 2.2 The presence of potential sources of ignition

In principle, before placing a bucket elevator on the market, its manufacturer will carry out an ignition hazard assessment in accordance with SR EN 80079-36 [6] specifications and will identify potential sources of ignition coming from technical equipment, capable to ignite an explosive atmosphere, as well as effective sources of ignition, in normal operation, in case of expected failures or in case of rare failures.

In addition to the possible ignition sources specified in SR EN 1127-1 [2], in the case of a bucket elevator there are also other ignition sources, namely:

- sources of ignition from related equipment, such as: hot, incandescent products, embers and/or explosion from related equipment;
- external sources of ignition due to smoking, maintenance, welding, cutting, etc.;
- sources of ignition that may arise from the transported product, if self-ignition or exothermic decomposition of the transported product is expected.

### 3 Fire hazards

In addition to the explosion hazard, a fire hazard to consider is combustible products and materials inside the bucket elevator. Also, the vertical orientation and closed construction of the elevator are favorable factors for the spread of fire and unfavorable for controlling a fire. An incipient fire developing in a bucket elevator where combustible dust is present can lead to a large fire or even a dust explosion.

For a correct assessment of the fire hazard in the case of a bucket elevator, the combustion characteristics of the combustible materials used (belts, buckets), the type of grain to be transported and the dust that is generated during transport must first be known.

Ignition sources can be introduced from the outside (such as incandescent nests, hot particles) or they can appear inside the elevator, their cause being for example hot bearings, scraping cups, heating of the drive or return pulley. It is also necessary to check grain stores at regular intervals in order to prevent possible self-ignition or exothermic degradation processes.

The characterization of the combustion behavior of the stored bulk product / dust is done through a parameter, called the BZ combustion class, through which at least an approximate estimate can be made if the deposited dust will ignite, or if the ignited dust will lead to the appearance of a smoldering burns or, on the contrary, it is possible to develop burning with an open flame. Taking this parameter into account, dust is classified into the following combustion classes:

- BZ 1 – no initiation;
- BZ 2 – short initiation, rapid disappearance;
- BZ 3 – localized combustion or smoldering;
- BZ 4 – propagation of smoldering combustion;
- BZ 5 – propagation of combustion in the form of a flame;
- BZ 6 – combustion in the form of an explosion.

If non-combustible dusts or dusts of class BZ 1 are handled, no fire protection measures are required in principle, provided that the bands and cups are made of non-combustible materials.
With regard to dusts classified as BZ 2 or BZ 3, in the presence of strips and cups made of non-combustible materials, the adoption and implementation of fire precautions are usually sufficient.

For dusts in combustion class BZ 4, a case-by-case assessment of fire protection and damage control measures is recommended, considering the presence of combustible equipment in the bucket elevator and the speed of propagation.

For BZ 5 dusts, both fire precautions and fire damage control measures must be considered, regardless of whether or not combustible materials are present inside the bucket elevator.

4 Fire and explosion prevention and protection of bucket elevators

In principle, the prevention and protection of bucket elevators against fires and explosions requires the adoption and implementation of technical and organizational measures, the most important of which are:

✓ preventing the accumulation of combustible dust from grains in layers or dust deposits;
✓ preventing the formation of explosive mixtures;
✓ prevention of ignition sources.

4.1 Fire prevention and protection

4.1.1 Fire prevention

The use of combustible materials in the components of bucket elevators will increase the risk of fire. Regarding the fire hazard, some component parts of the elevator, such as the casing, belt and buckets should be made of non-combustible materials or materials that do not support or propagate combustion.

If a bucket elevator is not in operation, no grain products should be stored inside it. Also, preventing dust explosions inside a bucket elevator by controlling all ignition sources will implicitly lead to fire prevention.

4.1.2 Fire protection

It can be done either manually or by using automated fire detection and extinguishing systems.

Manual extinguishing of fires by the personnel involved in servicing the bucket elevator can only be done if a fire is detected in an early phase, this cannot be applied if a fire manifests itself violently inside the elevator because, in addition to the actual fire hazard that may affect facility personnel, smoke will also appear, impeding firefighting efforts due to poor visibility. It should also be considered that especially materials made of plastic or rubber produce large amounts of black, toxic smoke when involved in a fire.

In terms of automatic fire fighting, the fire protection concept generally applied inside buildings, which involves the use of automatic sprinklers, is not effective in the case of bucket elevators. An effective automatic fire detection and extinguishing solution could be the installation of automatic sprinklers inside the bucket elevator, which will prevent the fire from spreading inside it and limit the overall consequences of a fire.
4.2 Explosion prevention and protection

Potentially explosive atmospheres will inevitably occur inside a bucket elevator used to transport grain products with a high dust content.

Combustible dust is expected to be present especially in the area of loading, transfer and unloading stations, where, implicitly, potentially explosive atmospheres also occur. Therefore, although in the case of bucket elevators transporting grain products, the occurrence of potentially explosive atmospheres cannot be prevented, however, by adopting appropriate technical and organizational measures, it is possible to reduce the probability of the occurrence and expansion of the explosive atmosphere inside the elevator with cups. Such measures include the following:

- the existence of dust removal systems in the loading, transfer and unloading stations;
- vertical transport speeds of cereal products should be as low as possible;
- avoiding as much as possible surfaces where dust can accumulate in layers;
- avoiding the return of transported grain to the foot of the elevator;
- removal of layers and dust deposits by using appropriate exhaust systems and installations;
- dust binding by using, for example, water or special oils that have a high flash point and do not contain volatile constituents;
- the existence of a cleaning program by applying which the dust deposited in layers or warehouses is removed at regular time intervals.

Therefore, preventing the occurrence of explosive atmospheres inside bucket elevators carrying grain products containing dust cannot be fully achieved, even if dust removal systems are installed which can reduce the dust concentration locally, but are unlikely to prevent the occurrence explosive atmospheres throughout the interior volume of the bucket elevator.

Due to this aspect, special attention must be paid to the prevention of effective ignition sources, especially those generated by the technical equipment in the bucket elevator. In this regard, the manufacturer of a bucket elevator intended for the transport of cereal products will carry out an ignition hazard assessment according to the probability of ignition sources, after which it will indicate the category of the bucket elevator, in accordance with Directive 2014/34/EU [7]. The manufacturer will put the bucket elevator on the market with the indication of its category and with the clear specification of the limits of use in relation to the intended destination and the parameters of the equipment (transport speed, maximum surface temperature, etc.).

The prevention of the occurrence of ignition sources can be achieved by adopting and implementing some technical measures, such as the selection of bearings and appropriate materials for making the component parts of the bucket elevator, as well as some organizational measures, such as for example the implementation of a service and maintenance program assumed by the user of the installation.

In the event of an explosion inside the bucket elevator, it is necessary that both the bucket elevator itself and the related parts involved in the production process are automatically disconnected from the power supply.

In order to prevent the initial explosions produced inside the bucket elevator from being transmitted to the interconnected process elements, explosion isolation is required at the entrance and exit to/from the elevator, as well as on other connecting lines. Explosion containment can be passive, achieved through the use of rotary valve or explosion diversion techniques, or active, through the use of extinguishing barriers or quick-acting valves.
## 5 Recommendations for the safe use of elevators

Table 1 shows some recommendations for the safe use of bucket elevators that are intended for the transportation of grain products.

**Table 1. Recommendations for the safe use of bucket elevators**

<table>
<thead>
<tr>
<th>No.</th>
<th>Requirement</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>General</td>
<td>All bucket elevators within the scope of this document should comply with the requirements contained in SR EN 80079-36:2016</td>
</tr>
<tr>
<td>2.</td>
<td>Assignment to equipment categories</td>
<td>Depending on the outcome of the ignition hazard assessment the manufacturer can indicate the internal and external category of the bucket elevator</td>
</tr>
<tr>
<td>3.</td>
<td>Temperature limits</td>
<td>These are the temperatures of the environment in which the bucket elevator can be located and the admissible temperatures of the product being conveyed.</td>
</tr>
<tr>
<td>4.</td>
<td>Mechanical design criteria</td>
<td>The strength of the bucket elevator in relation to internal over-pressure should be given but also wall thickness and construction details in relation to stability of the bucket elevator and to wear and corrosion. Preferably the casing should to be manufactured from non-combustible material.</td>
</tr>
<tr>
<td>5.</td>
<td>Speed</td>
<td>Typically 1 to 4 m/s, keep as low as practical</td>
</tr>
<tr>
<td>6.</td>
<td>Material combinations</td>
<td>Prevent combinations of light metal and carbon steel</td>
</tr>
<tr>
<td>7.</td>
<td>Pulleys</td>
<td>Crowned drive and return pulley design and if cover is required then use antistatic flame retardant material. If pulley is assembled out of several parts then measures should be taken to ensure integrity is maintained.</td>
</tr>
<tr>
<td>8.</td>
<td>Belt and chain: material and construction.</td>
<td>Use dissipative material (surface resistance on both sides &lt;3×10^8 Ohm™, conform IEC / TS 60079–32–1). Use fire retardant material. Adequate joint construction to prevent premature failure. Chains are to be selected to ensure acceptable low corrosion and wear.</td>
</tr>
<tr>
<td>9.</td>
<td>Bucket: material and construction</td>
<td>Dissipative/ conductive bucket material, according to IEC/TS 60079–32–1. is required for use with MIE values of less than 1 mJ, Attachment of buckets to belt - use self-locking nuts. The fixings are to be selected to ensure acceptable low corrosion and wear.</td>
</tr>
<tr>
<td>10.</td>
<td>Linings</td>
<td>Where linings are necessary for wear resistance they should have a maximum break-down voltage of 4 kV and a maintenance check program to ensure a minimum thickness of at least 8 mm to prevent propagating brush discharges.</td>
</tr>
<tr>
<td>11.</td>
<td>Earthing and bonding</td>
<td>All conductive fixed and moving parts should be earthed and bonded to limit ground resistances to &lt;=10^6 Ohm</td>
</tr>
<tr>
<td>12.</td>
<td>Electrical equipment</td>
<td>Equipment category inside and outside the bucket elevator should be appropriately selected depending upon the hazardous area.</td>
</tr>
<tr>
<td>13.</td>
<td>Prevention of deposits</td>
<td>Prevent horizontal ledges and surfaces. The boot part should be designed such that easy cleaning is possible.</td>
</tr>
</tbody>
</table>
14. Clearing between moving parts and casing

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clearing between moving parts and casing</td>
<td>≥ 25 mm, depending upon height and capacity. Specific situations (such as strong wind load) may require additional clearances or controls.</td>
</tr>
</tbody>
</table>

15. Shaft seals

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Information</th>
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</thead>
<tbody>
<tr>
<td>Shaft seals</td>
<td>Seals should be safe in accordance with SR EN 80079-36:2016</td>
</tr>
</tbody>
</table>

16. Bearings

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bearings</td>
<td>Preferably located outside the casing in accordance with SR EN 80079-36:2016</td>
</tr>
</tbody>
</table>

17. Belt tension system

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Information</th>
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</thead>
<tbody>
<tr>
<td>Belt tension system</td>
<td>Measures should be taken to ensure integrity is maintained in accordance with SR EN 80079-36:2016</td>
</tr>
</tbody>
</table>

18. Power transmission systems, clutches and couplings

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power transmission systems, clutches and couplings</td>
<td>Equipment outside the bucket elevator should be appropriately selected depending upon the hazardous area.</td>
</tr>
</tbody>
</table>

19. Brakes and braking systems

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brakes and braking systems</td>
<td>Anti-runback system is recommended for bucket elevators ≥ 10 m high and with capacity of ≥ 10 mc/h</td>
</tr>
</tbody>
</table>

In addition, to increase the level of security in the case of a bucket elevator, in table no. 2 additional recommendations are presented regarding the placement of some devices and sensors.

### Table 2. Additional recommendations for bucket elevators

<table>
<thead>
<tr>
<th>No.</th>
<th>Requirement</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Slip detection device</td>
<td>Monitor the speed of drive and boot pulley: at difference of &gt; 10 % activate alarm and stop bucket elevator.</td>
</tr>
<tr>
<td>2</td>
<td>Misalignment detection device</td>
<td>Monitor the horizontal belt movement. Should the distance to casing becomes too small for a maximum period of 5 s activate alarm and stop bucket elevator. If misalignment is detected by temperature detection device on friction plates alarm and stop should occur without time delay.</td>
</tr>
<tr>
<td>3</td>
<td>Bearing temperature detection</td>
<td>Monitor the bearing temperature. Should the bearing temperature increase significantly above the temperature in normal operation activate alarm and stop bucket elevator.</td>
</tr>
</tbody>
</table>

### 6 Conclusions

The use of technical equipment and protection systems, which are part of elevators with buckets intended for the vertical transport of grains, in environments where combustible dust is present presents a particular risk in terms of the occurrence of fires and/or explosions, a fact that influences largely the level of security of the workers involved in the production process. Due to this aspect, it is of particular importance to identify and implement protective and preventive measures to prevent the occurrence of fires and combustible dust explosions in the case of these grain transport facilities.

In the case of bucket elevators, the danger of explosion is associated with the presence of potentially explosive atmospheres generated by combustible dust deposited in the layer or swirled in the air, originating from the transported cereal products, and with the existence of an effective source of ignition. In addition, the fire hazard depends on the combustible products and materials inside the elevator, the combustion characteristics of the belts, buckets, the type of grain transported and the amount of dust generated.

The prevention and protection of bucket elevators against fires and explosions requires the adoption and implementation of technical and organizational measures, made concrete by preventing the accumulation of combustible dust from grains in layers or dust deposits, preventing the formation of explosive mixtures and preventing the appearance of effective sources of ignition.
References

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2. SR EN **1127-1** Explosive atmospheres - Explosion prevention and protection - Part 1: Basic concepts and methodology (2019)
6. SR EN ISO **80079-36** Explosive atmospheres - Part 36: Non-electrical equipment for explosive atmospheres - Basic method and requirements (2016)