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Study of a Dust Explosion in a Pharmaceutical Production Unit

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Many industries, such as coal, food, paper, metals, plastics, etc…, are exposed to the risk of dust explosions due to the specific characteristics of the powders handled. Companies need to understand these risks and the methods for preventing them in order to minimize their impact on people, the environment, and equipment.
To manage these risks, it is essential to understand the parameters associated with dust explosions, to identify the areas where explosive powder clouds can form under normal and abnormal conditions, and finally to identify potential sources of ignition. The study focuses on dust explosions in a pharmaceutical plant, analysing the conditions in which such phenomena occur and their consequences. The data collected was used firstly to characterize the dust explosion zones and then to apply the tools used to assess the risks of an explosion.Preventive measures have been proposed, including the selection of electrical equipment and the installation of an explosion vent.

1. Introduction

A wide range of industries and industrial applications involving many varied products such as coal, cereals, paper, foodstuffs, metals, rubber, pharmaceuticals, plastics, textiles, etc. (Abuswer et al., 2013) are continuously exposed to the risk of dust explosions due to the intrinsic characteristics of certain powders produced in these types of industries (Davis et al., 2011). The companies in question must be aware of the undesirable events associated with the processing and handling of these powders, as well as the different existing methods and practices, in order to anticipate this type of accident and reduce the effects on people, their environment, and their equipment (Ebadat, 2010).
To properly manage the risks of dust explosions, the following information are required (Ebadat, 2010): understanding the different parameters associated with dust explosions and identifying potential areas where explosive powder clouds may form under normal and abnormal working conditions.

2. Definitions and basic concepts

2.1 Explosions and dust dynamics

Explosions can be defined in two ways: the first as "a rapid rise in temperature and pressure, generating an audible pressure wave with spherical propagation," and the second as a chemical explosion involving "a sudden increase in pressure and temperature due to oxidation or other exothermic reactions" (Russell, 2016). Particulate matter is crucial, with BS 2955: 1958 categorizing particles under 1000 µm as powders and those under 76 µm as dust (Abassi et Abassi, 2007). NFPA 68 defines dust as particles with a diameter of 420 µm or less (BS, 1965), while this study adopts dust as any solid material under 1000 µm (ISO, 2016). Dust explosions occur when flammable particles combust rapidly in air, with their power linked to particle size (NFPA 68, 2022). Smaller particles, like wood under 1000 µm, burn faster due to increased surface area, making ignition easier with sufficient oxygen (Eckhoff, 2003). Understanding these definitions is key to grasping dust explosion dynamics.

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2.2 Dust explosion conditions and influencing properties

A dust explosion occurs when five conditions are met: combustible material, oxidizer, ignition source, dust suspension in the air, and confinement of the dust cloud (Ebadat, 2010). The first three form the 'fire triangle,' while the last two create a pentagon that aids pressure buildup (Russell, 2016). Dust properties, including composition and moisture, affect combustion dynamics, with smaller particles increasing explosion severity due to their larger surface area (Eckhoff, 2003). Turbulence in dust clouds mixes hot and cold segments, accelerating combustion, and as the temperature rises, the lower explosive limit decreases, requiring less dust concentration for an explosion (Skavland, 2018).The dust can only explode if its concentration is between the lower and upper explosive limits (LEL and UEL), leading to combustion products of CO_2 and water:

$$Combustible + comburant \ \rightarrow H_2O + CO_2 \quad (1)$$

Dust concentration affects explosion severity and minimum ignition energy; as concentration increases, the explosion rate rises until it peaks and then declines to zero. Conversely, mid-range explosion concentration initially decreases with increasing dust concentration, then rises again after surpassing a favorable concentration (C_{def}), eventually returning to its original level.

3. Characteristic parameters of the severity of an explosion

3.1 Maximum explosion pressure (P_{max}) and rate of pressure rise (dp/dt)

In a closed enclosure, the pressure from a dust explosion rises over time until reaching a maximum value (P_{max}), which indicates the explosion's severity; higher P_{max} values correspond to greater damage. The rate of pressure rise (dp/dt), influenced by factors such as the dust combustion rate and the material's characteristics, determines how quickly maximum pressure is reached. A higher pressure rise rate leads to more severe explosion effects, defined by the P_{max} value (Petit et Poyard, 2004).
The maximum rate of pressure increase is also related to the enclosure volume (V) through the cubic relationship:

$$\left(\frac{dp}{dt}\right)_{max} . V^{1/3} = Kst \quad (2)$$

Kst: characterizes the severity of a dust explosion based on its particle size and moisture content, allowing combustible dust to be classified; the higher the Kst, the more severe the explosion.

Table 1 - Classification of dust explosions as a function of Kst

Explosion class	Kst (bar.ms^{-1})	Characteristic of the explosion
S_{t1}	1-200	Low-medium explosion
S_{t2}	201-300	Strong explosion
S_{t3}	>300	Very loud explosion

4. Managing the risks associated with dust explosions

4.1 Identifying places where explosive atmospheres can form

Before identifying potential explosive atmospheres, it is essential to have a document detailing all finely divided flammable solids and their characteristics to assess their flammability and explosiveness (Petit et Poyard, 2004).

4.2 ATEX zoning and site data collection

Zone 20 is the area where a combustible dust cloud is always present; Zone 21 is where such an atmosphere may occur occasionally; and Zone 22 is where it is unlikely to occur or only for a brief period. Therefore, understanding these zones is essential for selecting the appropriate equipment and materials based on the characteristics of the dust. This work will also involve gathering the necessary data to study dust explosions in three critical areas within our company, as well as evaluating and determining the ATEX zoning for dust explosion risks. In light of this analysis, a primary area has been identified as presenting a significant risk of dust explosion: the weighing room. This room is used for weighing products and raw materials, quality control, and storage, with the upper zone being sensitive due to dust accumulation, which led the company to install a laminar flow ventilation system. The table includes all necessary study data for future calculations, focusing on amoxicillin trihydrate as the primary dust component.

Table 2: Data table

Data	Symbol	Value	Unit
Granulometry	D	<1	µm
Minimum ignition temperature of a dust cloud	MIT	520	°C
Explosion severity	Kst	192	bar/s
Minimum ignition energy of a dust cloud	MIE	100-200	mJ
Glass rupture pressure	P_{rup}	10^5	Bar
Weighing room volume	V	27.9	m^3

4.3 Risk assessment and ATEX zoning

The data for our dust explosion risk assessment, based on an INRS model (Skavland, 2018), is sourced from on-site surveys and the Gestis-Caratex Poussieres database:

- Preliminary analysis without taking into account existing prevention measures;
- Estimate occurrence frequency, identify ignition sources, and implement prevention measures before second zoning based on these parameters;
- Estimation of severity and explosion protection system.

Our assessment of the severity and explosion protection system identifies three possible cases for severity:

- No staff;
- Possibility of personnel;
- Fixed position near the source.

There are two possible cases for explosion protection systems:

- Protected installation or equipment;
- Unprotected installation or equipment.

This risk assessment study led us to:

- The frequency and severity of explosion risks are evaluated based on equipment, work processes, and prevention measures.
- Risk zones are classified as 20, 21, or 22 based on exposure to ignition and explosion risks.

To achieve this, preventive measures are taken, such as:

- Devices such as switches, lighting systems, electric scales and pallet trucks.
- The first cleaning and maintenance procedures are part of the preventive actions to maintain a safe working environment, with
- Specific zones classified according to risks.

Initial zones were redefined, allowing high-risk areas like Zone 20 to be reclassified as 'unclassified' once protected, with measures like ventilation systems to reduce ignition risk, and durability assessed in zone plans for worst-case scenarios, as illustrated in the following figure.

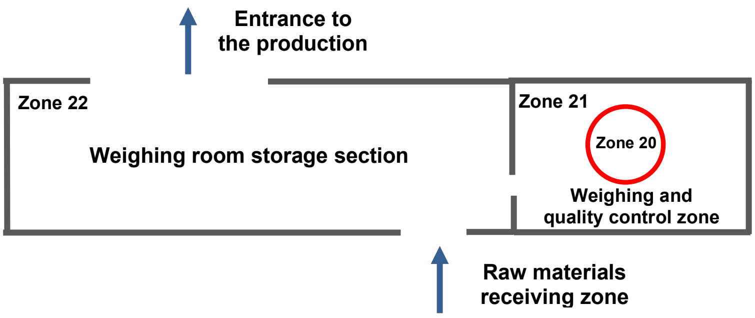

Figure 1: ATEX zoning for weighing rooms

The collected data on explosion risks and zoning will form the basis for the impact study and analysis of mitigation measures.

5. Explosion calculations, impact and recommendations

This section focuses on evaluating the consequences of a dust explosion in the three selected zones, followed by recommendations for equipment and materials based on the disaster's scale.

5.1 Calculating the power and effects of the explosion

The KINSELLA method determines the severity index based on three parameters, including ignition energy: High for primary explosions or condensed explosive, and Low for common ignition sources (hot surfaces, sparks).
The degree of containment is classified as: 1. Existing (open environment) and 2. Non-existent (closed environment).

Table 3: Kinsella grill

Ignition energy		Space requirements			Degree of containment		Index
Low	Strong	Strong	Low	None	Existing	None	
	*	*			*		7-10
	*	*				*	7-10
*		*			*		5-7
	*		*		*		5-7
	*		*			*	4-6
	*			*	*		4-6
*		*				*	4-5
	*			*		*	4-5
*			*		*		3-5
*			*			*	2-3
*				*	*		1-2
*				*		*	1

The severity index is 7 in the weighing room, with the higher index being selected in both cases.
Determining the energy released: The energy released by an explosion is calculated using the simplified Brode method:

$$E = 3.P_S.V \tag{3}$$

Such as: E: Energy released by the explosion (J), P_S: Explosion overpressure (bar), V: Volume of the enclosure (m^3).

Knowing that: Ps= 2*P_{rup},
Where P_{rup} is the rupture pressure of the enclosure (bar), the following numerical application is made for the Weighing room: E = 3 *2 * 105 * 27.9 = 16740*10^3J.
The calculation of excess pressure effects is then carried out using the 'multi-energy' method and the previously mentioned data are shown in the following table.

Table 4: Distances from excess pressure effects

weighing room				
x	1.5	3	5	8
r1	1.26	2.52	4.20	6.73
Ps'	0.35	0.15	0.055	0.03
tp1	350	150	55	30
tp	1.22	1.40	1.57	1.75

Where: r1 is the dimensionless distance, Ps' the relative overpressure (bar), and tp the explosion phase duration (s).
Based on the calculations, employees in the weighing room are exposed to overpressures exceeding 350 bar, while those more than 5 meters away may be affected by glass shards from the explosion.

5.2 Improvement measures to be implemented

After assessing the risks, we recommend analyzing equipment in high-risk areas to prevent explosions. When choosing equipment in these areas; it is selected based on its category (electrical or non-electrical) and temperature class, while zoning is defined to classify equipment according to its explosion risk (zones 20, 21, and 22).To protect equipment, strategies to prevent dust layer formation include sealing (IP6X) and internal overpressure systems. Additionally, annual cleaning of surfaces is recommended to eliminate potential ignition sources.

Expected improvements focus on enhancing equipment protection by isolating ignition sources and reducing explosion severity, particularly in mixers.
Examples of protected equipment include ventilation systems, motors, and mixers, which require specific protection levels such as IP6X, while devices like lighting and ventilation systems are specially designed for explosive environments (ATEX zones).
Protection measures for equipment in high explosion risk areas include equipment selection, sealing, internal overpressure, and safety recommendations based on INRS data.

Table 5: Category of equipment

Zone	Category	Level of protection	Equipment
20	1D	Very high	Possessing two independent safety measures that remain effective event during simultaneous independent failures.
21	2D	High	Suitable for normal operation and common disturbances, or for equipment that anticipates malfunctions.
22	3D	Normal	Suitable for normal operation

Table 6: Dust-tight equipment

Equipment that may be used	Required sealing
Zone 20/ Zone 21	IP6X
Zone 22	(Conductive dust) IP6X/ (Isolating dust) IP5X

Table 7: Temperature class

Temperature class	Maximal value (°C)	Temperature class	Maximal value (°C)
T1	450	T4	135
T2	300	T5	100
T3	200	T6	85

Differentiating protection modes for electrical and non-electrical materials during selection is crucial."

Table 8: Suppression of the explosive atmosphere

Internal deletion -symbol (p)	The penetration of surrounding atmosphere into electrical equipment enclosures is prevented by maintaining.
Oil immersion -symbol (o)	The electrical equipment is submerged in oil to prevent the penetration and ignition of an explosive atmosphere above the oil level or outside the enclosure.
Encapsulation symbol (m)	Parts that could spark and ignite an explosive atmosphere are encapsulated in resin to prevent penetration and ignition.

Table 9: Eliminating the source of ignition

Increased safety -symbol (e)	A protection method that implements measures to prevent excessive temperatures and arcs or sparks in electrical equipment during normal operation
Intrinsic safety -symbol (i)	An intrinsically safe circuit cannot ignite an explosive atmosphere under standard test conditions.

Table 10: Non-propagation of inflammation and internal security.

Explosion-proof envelope -symbol (d)	Ignition-prone parts are enclosed in a casing that contains internal explosions, similar to protection mode (d) for electrical equipment.
Powder filling -symbol (q)	Ignition-prone parts are fixed and fully embedded in filling material to prevent ignition of the surrounding explosive atmosphere.
Limited circulation envelope -symbol (fr)	Flow restriction protects by limiting the entry of explosive atmospheres into enclosures (concentration < LEL), applicable to equipment with ignition sources
Integrated safety	The principle is to set maximum criteria for speeds, materials, and energies to prevent ignition sources.

Table 11 : Construction safety

Construction safety -symbol (c)	The basic principle of this type of protection is to select equipment that does not normally contain a source of ignition.
Control of ignition source-symbol (b)	Install a control system with sensors to shut down the appliance if safety limits are exceeded.
Internal overpressure	St.rongly inspired by the protection mode (p) for electrical equipment.
Immersion in liquid-symbol (k)	The standard adopts the protection principle mode for electrical equipment, considering partial immersion and liquids other than oil.

Finally, by classifying ATEX zones and calculating the impact of such explosions, we were able to propose preventive measures to avoid ignition by selecting electrical equipment or installing protective vents.

6. Conclusion

The study focused on assessing the risks of dust explosions in critical areas of the installation. To achieve this, we first had to examine the company's activities by answering the question: How do you assess the risks associated with an explosive dust atmosphere?

We began by assessing the risks of dust explosions within the production unit. Based on the data collected, we were able to analyze the zones as well as the frequency and severity of such explosions, which subsequently led to their classification.

Using the results obtained, we calculated the effects induced by such explosions, including the affected radius, the mortality zone, and the congestion zone. We then proposed technical means of controlling the risks by selecting electrical equipment according to their protection category in line with the ATEX zoning or by installing an explosion vent.

Nomenclature

ATEX: Explosive Atmospheres
BS: British Standards Institution.
INRS: National Institute for Research and Safety.
ISO: International Organization for Standardization.
NFPA: National Fire Protection Association.

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