Explosive atmospheres risk assessment: a case study

Ing. MURE' Salvina
salvina.mure@aria.to.it

The case study is related to the risk assessment performed to fullfill ATEX regulations in a food industry.

The plant produces food stabilizers, ingredients, starches and gums.

The raw materials arrive to the plant as powders, contained in bags. The powders pass through hoppers to be homogenized and sieves and then they are mixed together and packed.

In each step of the manufacturing the movement of the powders can generate potential explosive atmosphere…

HOW TO EVALUATE THE EXPLOSION HAZARDS AND REDUCE IT?

The risk assessment was carried out in accordance with Italian law no. 81 of Apr. 9th, 2008 "*Attuazione dell'articolo 1 della legge 3 agosto 2007, n. 123, in materia di tutela della salute e della sicurezza nei luoghi di lavoro*" Title XI "Protection against explosive atmosphere" hereunder shown as D.Lgs. n. 81/08.

In accordance with what it is stated in attachment XLIX of D.Lgs. n. 81/08, for the classification of areas and working places, we refer to the following technical rules:

- CEI EN 60079-10-1 (CEI 31-87) "Explosive atmosphere – Part 10 - 1: Hazardous Area Classification and Control of Ignition Sources for Flammable Gases and Vapours" and CEI guide 31-35 and modifications;
- CEI EN 61241-10 (CEI 31-66) Electrical apparatus for use in the presence of combustible dust - Part 10: Classification of areas where combustible dusts are or may be present and CEI guide 31-36 and modifications.

For hazard analysis and risk assessment together with prevention and protection measures, we refer to the following rules:

- EN 1127-1:2011 Explosive atmospheres. Explosion prevention and protection. Basic concepts and methodology - specifies general design and construction methods to help designers and manufacturers in achieving explosion safety in the design of equipment, protective systems and components;
- CEI CLC/TR 50404:2003 "Electrostatics - Code of practice for the avoidance of hazards due to static electricity";
- UNI EN 13463-1:2009 "Non-electrical equipment for use in potentially explosive atmospheres. Basic method and requirements"

The italian laws above mentioned derive from EU directives and uptake international standards

In order to proceed with the explosion risk assessment, it's necessary to collect data about the facilities of the plant, the productive process, the presence of suction systems, and above all the characteristics of the raw materials that produce the explosive atmosphere.

For the purposes of this document, the main terms and definition are illustrated below:

- Lower Explosive Limit (LEL): the lowest concentration (percentage) of a gas or a vapor in air capable of producing a flash of fire in presence of an ignition source (arc, flame, heat). The term is considered to be the same as the lower flammable limit (LFL). At a concentration in air lower than the LEL are gas mixtures are "too lean" to burn. Methane gas has a LEL of 5%. If the atmosphere has less than 5% methane, an explosion cannot occur even if a source of ignition is present.
- Minimum ignition temperature of an explosive atmosphere: the lowest temperature of a hot surface that will cause a dust cloud, rather than a dust layer, to ignite and propagate flame.

- Explosion Index (K_{st}): explosive property measured in the laboratory to quantify the severity of a dust explosion. The K_{st} value is calculated as the equivalent pressure in a 1 m^3 sphere from the cube law (K_{st} value = cube root of volume x explosion pressure rise). The ST class is based on the K_{st} value as follows:
  - ST class 0 - K_{st} value = 0
  - ST class 1 - K_{st} value less than 200 bar m/sec
  - ST class 2 - K_{st} value between 200 and 300 bar m/sec
  - ST class 3 - K_{st} value greater than 300 bar m/sec;
- Minimum Ignition Energy (MIE): minimum amount of energy required to ignite a combustible vapor, gas or dust cloud.

In the following table, a list of the substances is shown with their characteristics.

Name of substances	Dust classification class	K_{ST} value [bar*m/s]	Minimum Ignition Energy [mJ]	Minimum Ignition temperarture [°C]	Glowing temperature [°C]	Lower Explosive Limit [g/m³]	Maximum explosion pressure [bar g]	Bulk Density [g/l]	Average size [µm]
AGAR	1	25	> 1000	380		240	7	500	150
CARRAGEENAN	1			430		125		700	75
CELLULOSE / CMC			>999	360 autoignition 170		60		400-600	75-125
CELLULOSE / HPMC	1	144	25-50	370		40-50	7,6		
CELLULOSE / MC		< 300		380 autoignition 170		30		200	
CELLULOSE / MC	1	80-160	29-110	>175	330-450	30	6-10		
EMULSIFIER / DATEM	1	116	20	280			7,83	520	150
EMULSIFIER / LACTEM								950	150
EMULSIFIER / MDG 40	1	71	15-30	300		30	6,7	900	150
EMULSIFIER / MDG 90 (kerry)	1	152	<10	280		<10	8,5	530	100-150
LBG	1	71	120	380		60	8,1	700-800	90
LBG	1	72	>10			500	6,9	700-800	90
MALTODEXTRIN	1	160	20-100	380		30	7,8	425-600	100-150
NOVATION 4600	2	202	60	240	320	30	10	500	10
PECTIN / HM	1	0-200	> 300	> 250 (layer)		30-300	6-10		40-150
POLIDEXTROSE	1	150	40	420		95	8	250	
PROTEIN / ANIMAL / GELATINE A			>1000	> 500				300-700	75-180
PROTEIN / ANIMAL / MILK / WHEY					440°C self ing temp	25 g/m3		650-800	
PROTEIN / ANIMAL / MILK / WHEY 60	1	39		440		30 g/m3	7.0	< 1000	
SALTS / CITRATE	1	21	>500				3.7		49
STARCH / MODIFIED / HOT SWELLING / WAXY MAIZE E-1422	1	150	100	420		60		650-800	75
STARCH / NATIVE / COLD SWELLING / WAXY RICE	1	114	>100	>470		30	8.7	650-800	75
SUGAR / FRUCTOSE	1	150	10	360		30	8	780-880	200
SUGAR / GLUCOSE	1	63	350			30-60	5.5	620	100
SUGAR / SUCROSE	1	172	10-25	>420 490 (layer)				680	
SWEETENERS / SUCRALOSE			400	390		16,5			
XANTHAN	1	84	>1000				7.6	650-850	180

With reference to the used raw materials, it is required the evaluation of the explodibility characteristics of each typology of powder:

Name: Novation 4600
LEL (g/m^3): 30
Average size (µm): 10
Absolute density (kg/m^3): 500
Layer ignition temperature T 5mm (°C): 240
Cloud ignition temperature Tcl (°C): 320
Humidity (%): 6,2
Mass humidity content (%): 6,2
Explosion overpressure (bar): 10
Kst (bar x m/s): 202
Explodibility class: St 2
MIE (mJ): 60
Conductivity: No

The explosion risk assessment requires 5 different steps:

1. Identification of explosion hazard and estimation of probability of occurrence of a hazardous explosive atmosphere;
2. Identification of ignition hazards and determination of the likelihood of occurrence of potential ignition sources;
3. Estimation of the possible effects of an explosion in case of ignition;
4. Evaluation of the risk and whether the intended level of protection has been achieved;
5. Consideration of the measures to reduce the risks.

The explosion risk assessment is evaluated by using a methodology with semi-quantitative indicators.

The analytical evaluation of risk can be determined in general accordance with the following formula:

$$R = P * C * D$$

where:

- R is the risk,
- P is the hazard factor, that is the probability of existence of the hazard,
- C is the contact factor, that is the probability that the hazard can cause damage,
- D is the damage factor, that is the entity of any damage that might occur.

STEP 1. Identification of explosion hazardous and determination of occurrence of a hazardous explosive atmosphere

The probability of occurrence of a hazardous explosive atmosphere is evaluated through Area Classification methods, according to EN 60079-10-1 and 61241-10. The correlation between hazard factor P and area classification is represented in the following table:

Hazardous Area	Description	P Index
Zona 0/20	An area in which an explosive gas/dust atmosphere in air is continuously present or present for long periods or frequently	3
Zona 1/21	An area in which an explosive gas/dust atmosphere in air is likely to occur in normal operation	2
Zona 2/22	An area in which an explosive gas/dust atmosphere in air is not likely to occur in normal operation and if it occurs it will exist only for a short time	1
Zona NE	An area in which an explosive gas/dust atmosphere in air never occurs	0
0,1,2 for gas, vapour 20,21,22 for dust		

STEP 2. Identification of ignition hazards and determination of the likelihood of occurrence of potential ignition sources

Then for each hazardous zone, it shall be determined which types of ignition sources are possible. The significance of all ignition sources that could come into contact with the explosive atmosphere shall be assessed.

The ignition effectiveness of all the ignition sources shall the be compared with the ignition properties of flammable substances:

- Minimum Ignition Energy (MIE),
- Minimum ignition temperature of an explosive atmosphere,
- Minimum ignition temperature of a dust layer.

This step shall result in a complete list of the effective ignition sources for each hazardous zone. Afterward the likelihood of occurrence of the potential ignition sources shall be assessed, taking also into account those that can be introduced e.g. by maintenance and cleaning activities.

The possible ignition sources to be taken into account are:

– Hot surfaces
– Flames and hot gases
– Mechanically generated sparks
– Electrical apparatus
– Stray electric currents, cathodic corrosion protection
– Static electricity
– Lightning
– Radio frequency (RF) electromagnetic waves from 104 Hz to 3 * 1011 Hz
– Electromagnetic waves from 3*1011 Hz to 3 * 1015 Hz
– Ionizing radiation
– Ultrasonics
– Adiabatic compression and shock waves
– Exothermic reactions, including self – ignition of dusts.

The correlation between the factor C and likelihood of occurrence of effective ignition sources is represented in the following table:

Presence	Description	C Index
Always	Sources of ignition which can occur continuosly or frequently	3
Sometimes	Sources of ignition which can occur in rare situations	2
Rarely	Sources of ignition which can occur in very rare situations	1
Never	Sources of ignition which can occur never	0

STEP 3. Estimation of the possible effects of an explosion

To estimate the possible effects of an explosion the following shall be considered, e.g.:

– Flames and hot gases;

– Thermal radiation;

– Pressure waves;

– Flying debris;

– Hazardous releases of materials.

The consequences of the above are related to the:

– Chemical and physical properties of the flammable substances;

– Quantity and confinement of the explosive atmosphere;

– Geometry of the surroundings taking into account obstacles;

– Strength of enclosure and supporting structures;

– Protective equipment worn by the endangered personnel;

– Physical properties of the endangered objects.

The correlation between factor D and the parameters used to evaluate the possible effects of explosion is represented in the following tables:

Hazardous Area	Description	D Index
Zona 0/20	An area in which an explosive gas/dust atmosphere in air is continuously present or present for long periods or frequently	3
Zona 1/21	An area in which an explosive gas/dust atmosphere in air is likely to occur in normal operation	2
Zona 2/22	An area in which an explosive gas/dust atmosphere in air is not likely to occur in normal operation and if it occurs it will exist only for a short time	1
Zona NE	An area in which an an explosive gas/dust atmosphere in air never occurs	0
0,1,2 for gas, vapour 20,21,22 for dust		

D Index will be added to the indexes in the table below (D'):

Parameters	Index		
	0,00	0,25	0,50
Workers presence (W_p)	Never	Occasional	Continuous
Dust explosion index (K_{ST})	≤ 200 bar*m/s	200 < K_{ST} ≤ 300 bar*m/s	> 300 bar*m/s
Gas explosion index (K_G)	≤ 500 bar*m/s	500 < K_G ≤ 1.000 bar*m/s	> 1.000 bar*m/s
Cloud volume (V_Z)	< 10 dm³	10 ≤ V_Z < 100 dm³	≥ 100 dm³
Dust layer depth (L_d)	≤ 5 mm	5 < L_d ≤ 50 mm	≥ 50 mm
Cloud Confinement (C_c)	Not confined	Partly confined	Completely confined

$$D' = D + W_p + K_{ST} + V_Z + L_d + C_c \text{ (dust)}$$
$$D' = D + W_p + K_G + V_Z + C_c \text{ (gas)}$$

STEP 4. Evaluation of the risk and whether the intended level of protection has been achieved

Another table, similar to the previous one, allows to determine the indexes of elements of the risk to be added to the product P * C * D '.

Parameters	Index		
	0	1	2
Workers presence (W_p)	Never	Occasional	Continuous
Dust explosion index (K_{ST})	≤ 200 bar*m/s	200 < K_{ST} ≤ 300 bar*m/s	> 300 bar*m/s
Gas explosion index (K_G)	≤ 500 bar*m/s	500 < K_G ≤ 1.000 bar*m/s	> 1.000 bar*m/s
Cloud volume (V_Z)	< 10 dm^3	10 ≤ V_Z < 100 dm^3	≥ 100 dm^3
Dust layer depth (L_d)	≤ 5 mm	5 < L_d ≤ 50 mm	≥ 50 mm
Cloud Confinement (C_c)	Not confined	Partly confined	Completely confined

Ultimately, therefore, the risk of explosion R is determined as follows:

$$R = (P*C*D') + W_p + K_{ST} + V_Z + L_d + C_c \text{ (dust)}$$

$$R = (P*C*D') + W_p + K_G + V_Z + C_c \text{ (gas)}$$

4. Evaluation of the risk

The classification of risk levels is determined by risk R calculated with the formula above.

In the table below are the hazard classes and their descriptions.

Risk Value R	Rischio	Description	Measures
$R \geq 18$	High	The probability of an explosive atmospheres is high, there are effective ignition sources and the exposure level is high, so with considerable damage to persons and property. The probability of propagation of the explosion is to be considered significant	Identify and implement immediate and urgent measures to prevent and control exposure to risk. The assessment will be repeated later.
$9 \leq R < 18$	Medium	The probability of the presence of explosive atmospheres is limited and there may be effective ignition sources. In case of explosion, the exposure level is moderate, then with moderate damage to persons and property. The probability of propagation of the explosion is to be considered limited.	The exposure is significant, it is necessary to bring improvements to the protection and decrease the risk. The maintenance of compliance rets with the employer and person in charge.
$1 \leq R < 9$	Low	The probability of presence of an explosive atmosphere is extremely limited, as well as the presence of effective ignition sources. The exposure level is low, so with limited damage to persons and property. he probability of propagation of the explosion is to be considered extremely limited.	Will be considered for risk reduction measures on the basis of an assessment ALARP (As Low As Reasonably Practicable)
Negligible		The presence of an explosive atmosphere is almost impossible or there are no ignition sources effectively. The level of exposure is negligible, so there are no damages to persons or property. The probability of propagation of the explosion is considered negligible.	No further action is necessary

STEP 5. Consideration of the measures to reduce the risks

The necessity of having an explosive atmosphere together with on effective ignition source, lead immediately to the basic principles for the reduction of risks:

a) **Prevention:**

- avoid or reduce explosive atmospheres; this objective can mainly be achieved by modifying either the concentration of the flammable substance to a value outside the explosion range or the concentration of oxygen to a value below the limiting oxygen concentration (LOC);
- avoid any possible effective ignition source;

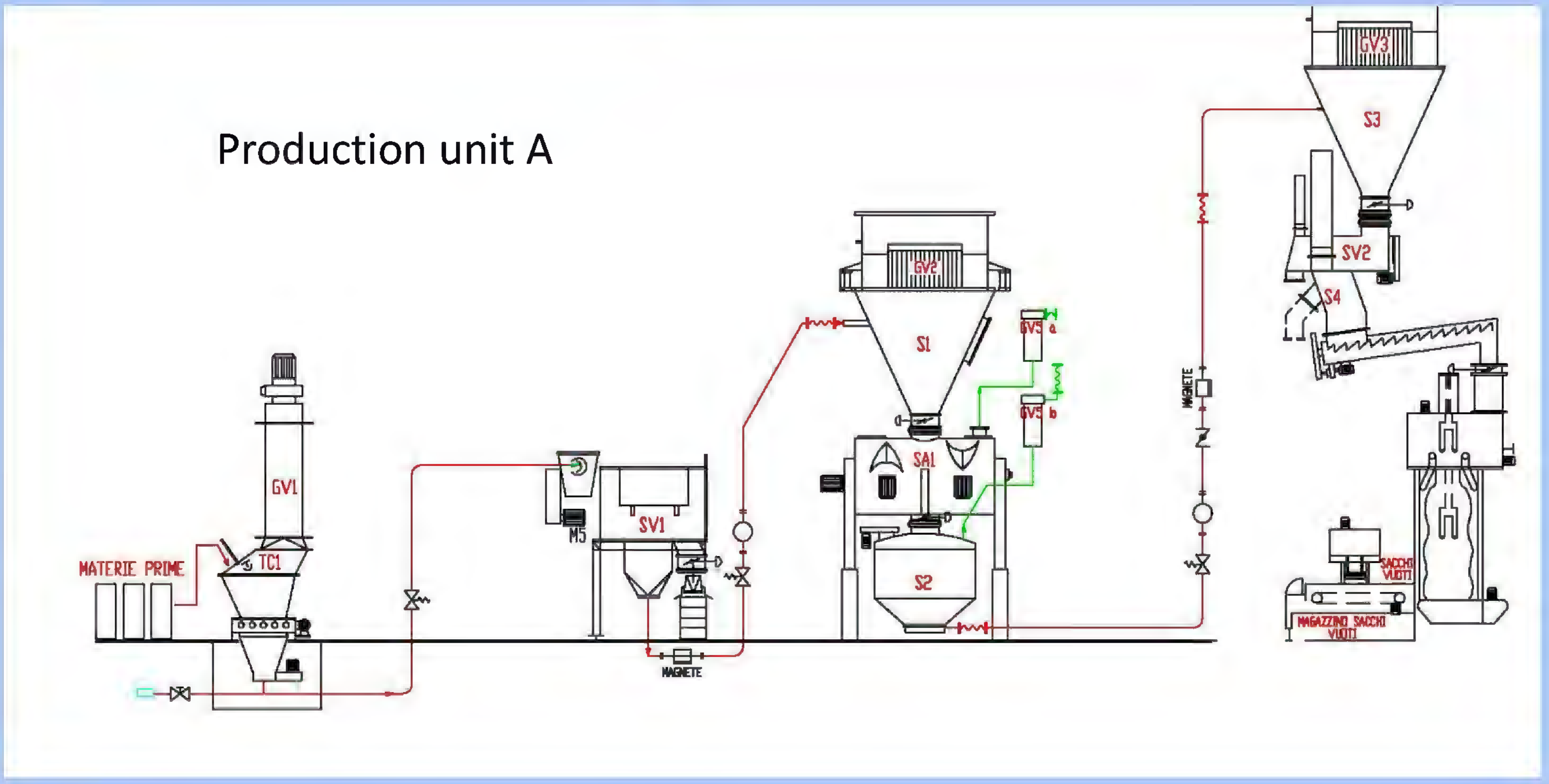
b) **Protection:**

- halting the explosion and/or limiting the range to a sufficient level by protection methods, e.g. isolation, venting, suppression and containment; in contrast to the two measures described above, here the occurrence of an explosion is accepted.

Area classification

Sources of release in

- Production unit (dust):
  - A, B e C
- Natural gas line (gas)
- Charging trucks unit (gas)



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The basic elements for establishing the hazardous zone types are:

1. the source of release – *a point or location from which a gas/liquid/dust may be released into the atmosphere so that an explosive atmosphere could be formed*;
2. the grade of release – there three basic grades of release, as listed below in order of decreasing frequency and likelihood of the explosive atmosphere being present: continuous, primary and secondary grade.

It is necessary, first of all, to determine the grade of release in accordance with the definitions, by establishing the likely frequency and duration of the release.

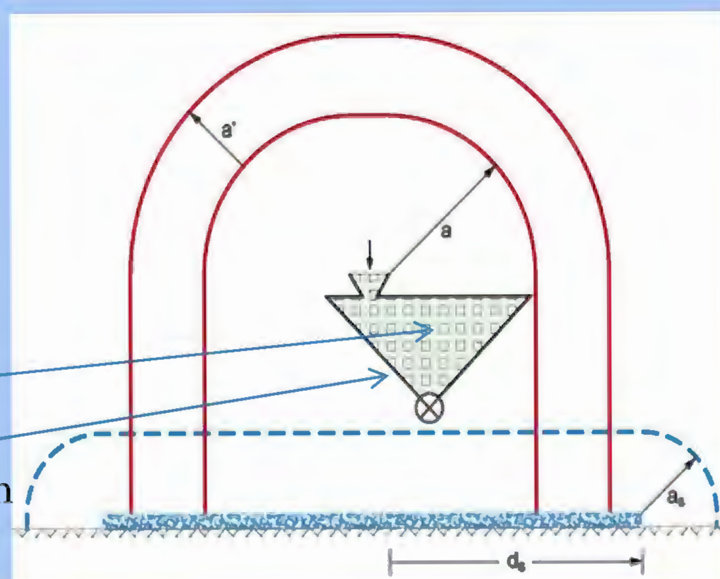
Having established the grade of the release, it is necessary to determine the release rate and other factors, which may influence the type and extent of the zone.

In the following table the area classification results for line A are shown:

Product line A			
Source of release	Grade of release	Zone	Note
Hopper TC1	Primary	Internal: 20 External: 22 , extension area 1,05 m	Loading with suction system always activated
Filter GV1	Secondary	Internal, dirty side: 20 Internal, clean side: 22 External: 2NE (Non hazardous area)	
Sieve SV1	Secondary	Internal: 20 External: 2NE (Non hazardous area)	The only source of release could be the door that is always closed. During cleaning operations, the sieve is electrically disconnected and suction system is activated.
Storage tank S1	Secondary	Internal: 20 External: 2NE (Non hazardous area)	The only source of release could be a drap door that is always closed
Connection S1-SA1	Secondary	Internal: 20 External: 2NE (Non hazardous area)	The connection is continuous.
Filter GV2	Secondary	Internal, dirty side: 20 Internal, clean side: 22 External: 2NE (Non hazardous area)	The filter has no sources of release. When the maintenance is performed, ad hoc operating instruction has adopted in order to avoid the formation of clouds potentially explosive.
Mixer SA1	Secondary	Internal: 20 External: 2NE (Non hazardous area)	The only source of release could be the door, but when it is opened the mixer is electrically disconnected and suction system is activated.
Connection SA1-S2	Secondary	Internal: 20 External: 2NE (Non hazardous area)	The connection is continuous.
Filter GV5	Secondary	Internal, dirty side: 20 Internal, clean side: 22 External: 2NE (Non hazardous area)	The filter has no sources of release. When the maintenance is performed, ad hoc operating instruction has adopted in order to avoid the formation of clouds potentially explosive.
Storage tank S2	Secondary	Internal: 20 External: 2NE (Non hazardous area)	The only source of release could be a drap door that is opened only during cleaning and maintenance operations. In these cases, the storage tank is electrically disconnected and suction system is activated.
Storage tank S3	Secondary	Internal: 20 External: 2NE (Non hazardous area)	The only source of release could be a drap door that is always closed
Connection S3-SV2	Secondary	Internal: 20 External: 2NE (Non hazardous area)	The connection is continuous.
Filter GV3	Secondary	Internal, dirty side: 20 Internal, clean side: 22 External: 2NE (Non hazardous area)	The filter has no sources of release. When the maintenance is performed, ad hoc operating instruction has adopted in order to avoid the formation of clouds potentially explosive.
Sieve SV2	Secondary	Internal: 20 External: 2NE (Non hazardous area)	The only source of release could be the door that is always closed. During cleaning operations, the sieve is electrically disconnected and suction system is activated.
Storage tank S4	Secondary	Internal: 20 External: 2NE (Non hazardous area)	The only source of release could be a drap door that is opened only during cleaning and maintenance operations. In these cases, the storage tank is electrically disconnected and suction system is activated.
Packaging	Secondary	Internal: 20 External: 2NE (Non hazardous area)	Closed room.

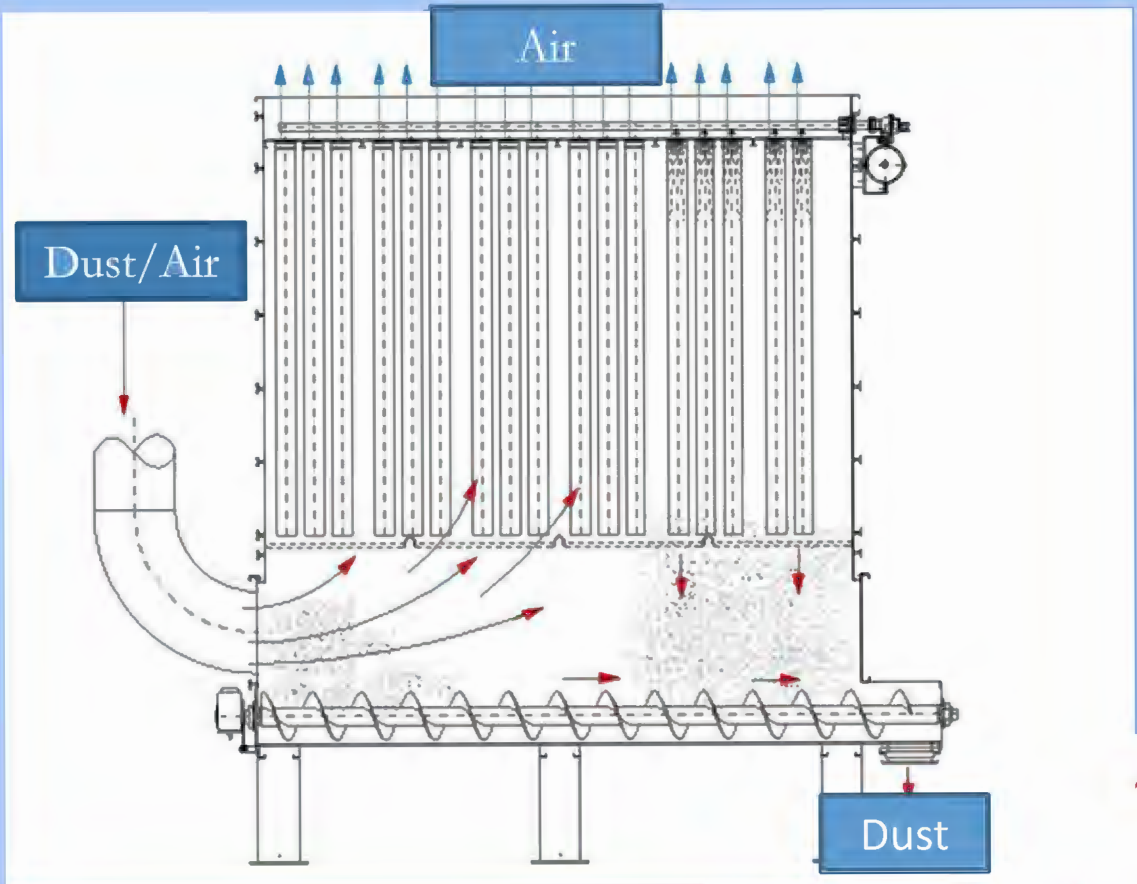
Hopper and typical equipment: suction system, shelf for bags, ecc.

Area classification for hopper

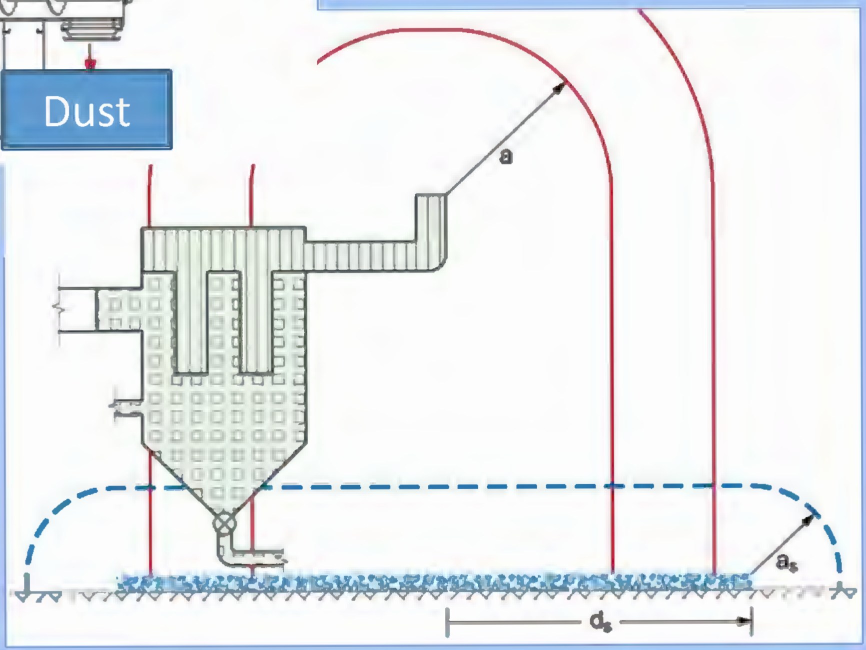


Internal: 20

External: 22 , extension area, a = 1,05 m



This a scheme of cartridge filter. In Hopper filter GV1, the dust collected is sent to the production line



Area classification for filter

Ignition sources analysis

In order to analyze the potential ignition sources, it is necessary to refer to the technical documentation of equipments, containing also the risk analysis and, in particular, the ignition sources analysis, that the manufacturer must do in normal condition (NC), rare malfunction (RM) and very rare malfunction (RMF), according to CE Declaration of Conformity (Machinery Directive 2006).

The following table shown part of ignition sources analysis for hopper:

Hopper TC1				
Ignition sources (EN 1127-1)	Presence (Yes/No)	Reasons	Effictive (Yes/No)	Reasons
Hot surfaces	No	Not present. The temperature conditions inside and outside of the hopper are of an order of magnitude lower than the ignition temperature of the dust treated.	Never	--
	Yes	However, one can not exclude the presence of high temperature surfaces for the moving parts due to friction in case of failure.	Never	The hopper is subject to periodic maintenance quarterly. The source of initiation occurs in case of failure (eg seizure of a bearing), but with the adequate maintenance such event is not relevant, which is deemed not effective for the source of ignition.
Flames and hot gases	No	The possible presence of flames and hot gases could be due to hot work during maintenance operations. However, it excludes this occurrence beacuse "Hot work permit" procedure are adopted.	Never	--
Mechanivally generated sparks	No	Possible mechanical sparks may be generated outside due to the use of unsuitable tools. In this regard, we adopt suitable tools will be drawn up and operating procedure for this purpose.	Never	--
	Yes	Can not be excluded that the friction of the moving parts and spark generating heat, as the speed of the same is greater than 1 m / s (paragraph 6.4.3 of the UNI EN 13463-1:2009).	Sometimes	In normal condition, it is excluded the friction between metal parts. In case of failure, can not be excluded that event, and having regard to the speed, the source of ignition may be effective.

Estimation of the possible effects of an explosion

Taking into account the parameters for Cloud volume V_z and Cloud confinament C_c, the Indices of damage D was calculate. The main results are shown in the following table:

Product line A					
Source of release	Zone	D	Vz Cloud volume [dm³]	C_C Cloud confinament	D'
Hopper TC1	Internal: 20	3	358 (0,5)	PartlyConfined (0,25)	5
	External: 22	1	>100 (0,5)	Not Confined (0)	2
Sieve SV1	Internal: 20	3	N.P. (0,5)	Completely Confined (0,5)	5
Connection S1-SA1	Internal: 20	3	46 (0,25)	Completely Confined (0,5)	5
Mixer SA1	Internal: 20	3	1200 (0,5)	Completely Confined (0,5)	5
Connection SA1-S2	Internal: 20	3	131 (0,5)	Completely Confined (0,5)	5
Storage tank S2	Internal: 20	3	1349 (0,5)	Completely Confined (0,5)	5
Connection S3-SV2	Internal: 20	3	39 (0,25)	Completely Confined (0,5)	5
Sieve SV2	Internal: 20	3	N.P. (0,5)	Completely Confined (0,5)	5

Evaluation of the risk

The results of risks for each equipment are shown in the following table:

Product line A							
Equipment	Zone	P	C	D'	Vz Cloud volume	C_C Cloud confinamen	Risk
Hopper TC1	Internal: 20	3	2	5	2	1	High (35)
	External: 22	1	2	2	2	0	Basso (8)
Sieve SV1	Internal: 20	3	2	5	2	2	High (36)
	External: 2NE						Negligible
Connection S1-SA1	Internal: 20	3	3	5	1	2	High (50)
	External: 2NE						Negligible
Mixer SA1	Internal: 20	3	2	5	2	2	High (36)
	External: 2NE						Negligible
Connection SA1-S2	Internal: 20	3	3	5	2	2	High (51)
	External: 2NE						Negligible
Storage tank S2	Internal: 20	3	2	5	2	2	High (36)
	External: 2NE						Negligible
Connection S3-SV2	Internal: 20	3	3	5	1	2	High (50)
	External: 2NE						Negligible
Sieve SV2	Internal: 20	3	2	5	2	2	High (36)
	External: 2NE						Negligible

Identification of prevention and protection measures

If ignition hazards are possible and the specific measures cannot be implemented, the equipment, and the protective systems and components shall be designed and constructed in such a way as to limit the effects of an explosion to a safe level.

Such measures could be:

- Explosion resistant design, see EN 14460;
- Explosion venting, see EN 14797;
- Explosion suppression, see EN 14373;
- Explosion isolation, see EN 15089, EN ISO 16852.

These measures generally refer to the mitigation of hazardous effects from explosions inside equipment, protective systems and components.

Identification of prevention and protection measures

In the following table, the main prevention and protection measures identified are shown:

Equipment	Preventive measures	Protection measures	Residual risk
Hopper TC1	Inverter to reduce the speed of moving parts under the 1 m/s.		Negligible
Sieve SV1	Periodic inspection of moving parts in order to detect signs of wear and deformation. In order to avoid cracks and delamination of metal parts.	Installation of suitable systems for suppression and explosion venting of combustion gases	Low
Connection S1-SA1	Replacement the connection with one in conductive material.		Negligible

Panels explosion venting

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Conclusion

The risk assessment approach described taken into account the main requirement steps indicated by EN 1127:1 standard and by law no. 81 of Apr. 9th, 2008; moreover, this approach allows to quantify the effectiveness of prevention and protection measures in order to reduce the risk.

The main difficulty of this analysis is to have the technical documentation, especially when the equipment are installed before the Machinery Directive. In this case, on-site visits with the technical staff should be made.

The results of this analysis should be included in the Document of Explosion Protection, mandatory for Italian and European law.

A similar approach can also be used for workplaces where there may be flammable gases, vapors and flammable liquid.