

Hazardous Area Classification due to Combustible Dust Atmospheres and Layers: Avoiding Common Mistakes

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In areas and workplaces where combustible dusts are produced, handled or stored, Hazardous Area Classification is required to assess the likelihood of formation of a dust explosive atmosphere. The resulting dust zoning is of paramount importance in deciding the type and protection modes of electrical and non-electrical apparatuses to install in those areas. Dust zoning is a widespread and well-known technique, covered by dedicated technical Standards such as IEC 60079-10-2 and NFPA 499. As such, it also represents the first step for a dust explosion risk assessment, therefore its quality and completeness are of the utmost importance in order to achieve a high-value, robust explosion risk management. The behavior of fires and explosions from dust clouds or layers is strictly dependent on the chemical-physical characteristics of the dust: the first section of this paper shall analyze those characteristics, and how their variations affect the classification of areas. After this overview, the paper shall illustrate the most common misconceptions and mistakes that can be encountered in Hazardous Area Classifications and provide insights and suggestions on how to avoid them.

1. Introduction: why is Hazardous Area Classification important?

Over the last couple of decades, the process industry has witnessed an increased level of awareness towards the hazards of combustible dusts fires and explosions. As it has often happened with safety related matters, this trend has likely started following some dreadful accidents involving combustible dusts, resulting in a great number of fatalities and ruinous economic costs (CSB 2006).

The most notable of these incidents is the case of Imperial Sugar refinery, located in Pont Wentworth, Georgia: the explosion took place in February 2008 and resulted in 14 fatalities and 36 injured people (Vorderbrueggen, 2011). Other examples include the polyethylene dust cloud explosion at West Pharmaceuticals, North Carolina, in 2003 (Coombs, 2004), which resulted in 6 fatalities, and the aluminum dust explosion at In-Metal Products at Kunshan, China, in 2014, that caused 146 deaths and 114 wounded (Li et al., 2016).

In an effort to provide a general approach to dust hazards identification and management, regulatory bodies all over the world have been releasing a number of Standards and Recommended Practices on combustible dusts, such as NFPA 652 "Standard on the Fundamentals of Combustible Dust", IEC 60079-10-2 "Classification of areas - Explosive dust atmospheres" and CCPS "Guidelines for Combustible Dust Hazard Analysis".

Despite the differences in methodology that may exist between the different Standards, they all agree that the first step for the correct management of the explosion risk is to define the probability of occurrence of an explosive dust atmosphere, that is to identify the hazard and assigning it a frequency. This step, generally referred to as Hazardous Area Classification (HAC), results in the definition of Zones for the plant (hence, the term zoning), and provides the input values for the subsequent analyses, typically an ignition risk assessment.

2. PSI – Process safety information

When performing a dust explosion risk assessment, data on the chemical-physical characteristics of the dust is fundamental because fire and explosion properties may vary significantly from material to material and are strongly dependent on a powder's moisture content, particles size and particle shape as well as operating conditions such as elevated temperature and pressure.

NFPA 652 (Chapter 5) requires that a determination should be made regarding the explosibility of powders/dusts that could be handled/processed or otherwise generated within the plant. If the dusts are determined to be explosive or combustible, additional testing must be performed, as required, to acquire the data necessary to support the Dust Hazard Analysis (DHA) that must be conducted.

The Annex of the standard lists five important tests that should be conducted. These are:

- Minimum Ignition Energy – MIE;
- Minimum Ignition Temperature of the dust cloud and the layer (MIT, LIT);
- Minimum Explosible Concentration – MEC;
- Explosion severity (i.e., Deflagration Index K_{st} and Maximum Explosion Pressure P_{max});
- Limiting Oxygen Concentration – LOC, if inerting is used.

2.1 Factors influencing explosibility

Some of the above-mentioned explosion parameters of the dust (e.g., MIE, MEC, K_{st}) can be influenced by external parameters related to the process; it is therefore necessary to carefully evaluate the operating conditions since their variation could lead to a change in the reference parameters on which the DHA is based, leading to dangerous underestimations of the risks associated with the presence of combustible dust. The main factors influencing explosibility are discussed below.

Moisture content

The amount of moisture absorbed within a particle or adhering to the particle surface can greatly affect the relative dust explosibility hazards in several ways. Materials with moisture contents below 5 % are considered “dry” and will exhibit the most extreme ignition sensitivity and explosion severity. In addition, the degree of wetness of a particle’s surface can increase the particle’s electrical conductivity and reduce its propensity to create and retain electrostatic charge. Surface moisture can also facilitate agglomeration of fine particles and thereby increase the dust suspension’s apparent average particle size.

Particle size

In general, the smaller the particle size of a dust the greater the dust explosion hazard. Both ignition sensitivity and explosion severity are adversely affected by reduced particle size. However, below particle sizes of about 200 Mesh (75 micron) the changes are less. As a result, ISO/IEC 80079-20-2 (2016) standard dust hazard testing is conducted on the “worst” dust sample, screened at 200 Mesh.

Process conditions

All flammability data are determined using accepted test methods such as ISO/IEC (2016) methods under standard conditions, so that materials can be compared. However, the process conditions, such as temperature and pressure, can have a profound effect on the behaviour of a material. Many processes run at elevated temperatures, and this will affect the hazards in the plant. For example, the MIE is especially strongly influenced by the temperature, and a dust that is only moderately sensitive at room temperature may be extremely sensitive at an operating temperature of 100 °C.

In order to maintain a cloud of flammable dust mixed with air, turbulence must be present to prevent the dust from settling out. This is taken into account during the standard testing of powders. However, there are situations where the turbulence level is exceptionally high, leading to a more severe explosion than would be predicted based on the standard test results for explosion severity. One common situation where this may be the case is when an explosion can propagate through connecting pipework from one vessel to another. This will lead to a more violent explosion in the pipe and in the downstream vessel (due to “flame jet ignition”). In addition, connected vessels may experience “pressure piling”, where the pressure in the downstream vessel increases because of the flow from the explosion in the upstream vessel (Lunn et al., 1996). The second explosion will be more severe (proportional to the absolute pressure at the start of the explosion) than one starting at atmospheric pressure. Protection measures designed using standard design rules are unlikely to be adequate to protect against explosions caused by flame jet ignition and/or exhibiting pressure piling.

The presence of flammable vapours or gases in a flammable dust cloud leads to what is called a “hybrid mixture”. IEC 60079-10-2 (2015) defines the hybrid mixture as a combined mixture of a flammable gas or vapour with a combustible dust or combustible flyings (it is recommended that a hybrid mixture is considered explosive if the concentration of the gas/vapour exceeds 25 % of the LFL or the concentration of the dust exceeds 25 % of the MEC). This hybrid mixture may behave differently than the gas/vapour or dust individually: the MIE of a hybrid mixture can be as low as that of the vapor/gas while the vapor/gas concentration remains below the LFL; similarly, the explosion severity (Deflagration Index) will generally increase above that of the dust alone because of the influence of the turbulence that is a characteristic of flammable dust clouds.

3. Common mistakes and misconceptions in Hazardous Area Classification

Given the above, it is therefore clear that proper, sound dust zoning of a plant or equipment is of the utmost importance in the overall framework of combustible dust hazards management, as any errors in this phase may gravely affect the quality of the overall explosion risk assessment. In the following sections, the Zones definitions from IEC 60079-10-2 "Classification of areas - Explosive dust atmospheres" are used:

- ZONE 20: a place in which an explosive dust atmosphere, in the form of a cloud of dust in air, is present continuously, or for long periods or frequently.
- ZONE 21: a place in which an explosive dust atmosphere, in the form of a cloud of dust in air, is likely to occur in normal operation occasionally.
- ZONE 22: area in which an explosive dust atmosphere, in the form of a cloud of combustible dust in air, is not likely to occur in normal operation but, if it does occur, will persist for a short period only.

3.1 Over-zoning is OK

The term over-zoning is used, in this context, to indicate the widespread practice of classifying vast areas of the plant into Zone 22 or 21 (Zone 20 outside of equipment is rarely applied).

In principle, such an approach can be acceptable where multiple emission sources are confined in a well-defined and relatively small area, such as a process room surrounded by solid walls. In practice however, over-zoning usually entails more negative than positive aspects, such as:

- Acceptance of poor dust control – when the whole working area is classified, personnel tend to accept poorer levels of housekeeping, under the misconception that "a little more dust" will not affect the already classified area. Given that good housekeeping and cleaning practices are the primary means for controlling dust explosion risks outside the equipment, such acceptance should not be encouraged or tolerated.
- Increased severity of explosion consequences – this aspect is strictly related to the previous one, in the sense that when accepting greater amounts of dusts to be dispersed (or deposited as layers) in the working environment, at the same time the amount of combustible dust available to fuel a possible secondary explosion is increasing, thus worsening the severity of the explosion.
- Challenges in controlling all ignition sources – the methodology for Dust Hazard Assessment states that, when elimination of the flammable atmosphere is not feasible, then the safety of the plant shall be achieved through control of ignition sources. It goes without saying that effective control and mitigation of ignition sources is much more impractical over a whole room than over a 1- or 2-meter-wide hazardous area.
- Increased costs and maintenance issues – equipment for classified areas shall comply with stricter regulations than regular ones (i.e., ATEX Directive 2014/34/EU) and are therefore more expensive to purchase. In addition, equipment for classified areas carries with them specific requirements for maintenance and inspection, that will burden on the workload of the maintenance team of the plant.

Performing a Hazardous Area Classification without proper consideration of the source and rate of release and the influence of ventilation (or dust extraction) generally leads to over-zoning, and the same may happen when one is incentivized to be overly-conservative. Over-zoning should not be used as a justification for lack of process knowledge or as an excuse to normalize poor dust management practices in the plant.

3.2 If there is some dust, a Zone must be assigned

When performing site-based Hazardous Area Classifications, the assessor usually assigns the zone by relying heavily on the amount of dust that can be seen outside a piece of equipment. As practical as this is, one must always bear in mind that airborne dust clouds become flammable once they reach their lower explosion limits, called MEC (Minimum Explosible Concentration, similar to the LFL of gases and vapors). MEC values for the most common combustible dusts vary between 30 g/m³ and 100 g/m³ (Eckhoff, 2003): to try to make practical and tangible sense of these numerical values, consider that a cloud of dust with a concentration equal to 40 g/m³ prevents an observer from seeing the light of a 25 W bulb placed 2 meters away (Figure 1). It is important to keep this in mind when deciding zone extents: just because airborne dust can be seen in the area, that does not necessarily mean it is flammable. Outside of equipment, the flammable concentration will diminish quickly as dust settles; furthermore, coarser and more dense dust settles faster. Dust with high MEC values will produce very small zones, unless the release is very large.

3.3 If no dust is present, then no Zone shall be assigned

It may happen that no Zone is assigned during Hazardous Area Classification due to the fact that no dust was seen in the working area during site inspection (or according to plan personnel). While the absence of dust clouds and dust layers is proof of proper plant/equipment design and good housekeeping, the identification of potentially hazardous areas shall consider not only normal operation, but also abnormal operation and start up / shut-down conditions (with the only exceptions of catastrophic failures).

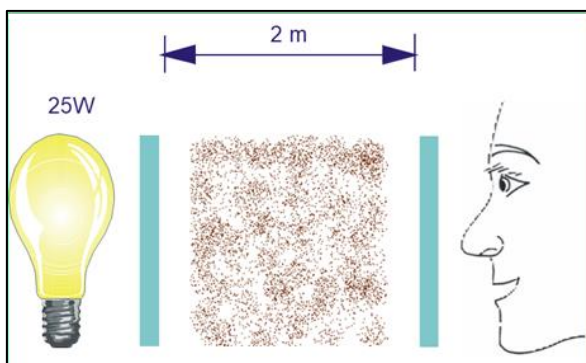


Figure 1: Practical example of a flammable dust cloud (Eckhoff, 2003)

It is responsibility of the assessor then to identify those cases where a piece of equipment or a particular manual procedure may generate some kind of dust release. Some explicative examples are given below:

- Opening a bag filter to clean or replace the filtering sleeves may cause some dust to be released into the working environment;
- Periodic inspection and maintenance of normally enclosed volumes, such as piping or silos, may generate dust clouds outside those pieces of equipment;
- Tears and breaks in soft fabric elements (cloth) or light plastic elements (connecting bellows) will become emission sources for the dust contained inside;
- Failure of mechanical extraction or ventilation systems will result in a cloud/layer formation, where normally no hazardous area is expected.

3.4 No Zone inside equipment

When performing a Hazardous Area Classification, one of the terms that is more commonly used is “emission source”, so it comes as no surprise that a great deal of attention is given to points and locations of the plant where releases are expected. This approach to the assessment, however, should not prevent the assessor from appreciating the broader purpose of a Hazardous Area Classification, that is “to give an assessment of the likelihood of an explosive dust atmosphere occurring” (IEC 60079-10-2, 2015).

The internal volumes of dust handling equipment should not be exempted from zoning: inside a dust containment, dust is not released into the outside atmosphere but as part of the process, continuous dust clouds may form inside the containment. These clouds may exist continuously or may be expected to continue for long periods or for short periods. The frequency of their appearance depends on the process cycle, abnormal operation and the start-up and shut-down conditions. It is also worth noting that most dust explosion initiate inside process equipment, so it is of the utmost importance that thorough explosion management is applied also to the inside volumes of dust handling equipment (Eckhoff, 2003).

3.5 Dust handling equipment should all be Zone 20 inside

In opposition to the case described in the previous paragraph, an excessively conservative (and sometimes poorly reasoned) approach could lead to classify all internal volumes of dust handling equipment as Zone 20. This line of action is somewhat akin to what described in paragraph 3.1, regarding over-zoning, and entails similar pros and cons.

Given that Zone 20 is assigned when explosive atmospheres (having a dust concentration in air equal to or greater than the MEC value) are present continuously or frequently, it is possible to acknowledge that not every piece of dust handling equipment falls in this definition, as for example:

- Slow moving screw conveyors and drag link conveyors, that are purposefully designed to minimize dust turbulence;
- Mixers used for water-wet products, such as bakery dough machines;
- Flood fed cone mills;
- Silos and bins containing coarse solid material, where dust fraction is low.

3.6 I only use the equipment 5 hours a year, so it's Zone 22 inside

Standards and Guidelines for Hazardous Area Classification tend to define the frequency values for the definition of Zones, and such suggestions may come in handy when in doubt about what type of Zone to assign to a particular emission source. When using these suggested frequencies, it is important to keep in mind that

the ultimate goal of an explosion risk assessment is to avoid the simultaneous presence of an explosive atmosphere and an ignition source (effectively disrupting the fire triangle). For this reason, it is considered more appropriate to understand and apply the frequency term not in the absolute sense of 'hours/year' of the operation that generates the dust cloud, but in the relative meaning of 'hours of presence of dust cloud/duration of the operation'. Let's consider a practical example: a unit operation is performed once a year, and usually lasts 5 hours. If a flammable dust cloud is present within the machine for the whole 5 hours (or most of it), then the proper zoning would be Zone 20, since the explosive atmosphere is present continuously while the machine is up and running (and can provide potential ignition). It would be a blatant misunderstanding of Hazardous Area Classification principles if a Zone 22 were to be applied.

3.7 I can apply the same Zoning as another similar plant

In the never-ending effort to reduce the economic costs of plant operations, some people may be tempted to copy / paste the zoning studies and results from one plant to a very similar other, taking comfort and justification from the fact that the same materials and the same processes will most certainly result in the same risk levels. Clearly, it is not suggested that the wheel must be reinvented every time a new plant is designed and built, but many different factors come into play when performing a Hazardous Area Classification, and their impact on the final assessment is not always straightaway recognizable. The most subtle aspects to catch may reside in:

- Variances in staff skill level, training and field experience;
- Differences in the quality of fabricating materials;
- Changes in raw material properties and suppliers, as well as differences in product specification such as particle size;
- Differences in operating procedures, maintenance practices and housekeeping levels;
- Applicability of different local and national requirements and standards.

3.8 Zoning only needs to cover routine operations

As stated in the discussion of some previous paragraphs, the identification of potentially hazardous areas shall consider not only normal operation, but also abnormal operation and start up/shut-down conditions. Non routine operations could be, for example, sampling, cleaning, and emergency repairs.

The only exceptions to the above statement are catastrophic failures, occurrences which exceed the design parameters of the process plant and control system, resulting in major release of flammable material. The management of risk arising from catastrophic failures goes beyond the scope of a Hazardous Area Classification and is dealt with in more appropriate branches of a Process Safety Management System.

Zoning is an important part of proper explosion risk management, and, as such, should encompass all foreseeable phases of a plant lifecycle: performing a zoning exercise only for routine operations would leave the plant "blind" to the portion of the risk arising from non-routine operations.

3.9 If inerting is in place, then no Zone is required

Working under inert conditions is a good and proven preventive method for managing explosion risk, as it allows to reduce or even eliminate the probability of occurrence of an explosive atmosphere. That said, the fact alone that an inert gas flows through the dust processing system is not enough to ascertain the absence of an explosion hazard in the inside volumes. First, proper consideration should be given to the reliability of the inerting system, as the failure of this system will definitely result in the formation of an explosive atmosphere. The reasoning on reliability must also be extended to measuring instruments, such as oxygen sensors, that are often prone to fouling defect and drifts in measure. In addition, dust handling equipment is rarely gas tight, so leakages of inert media (in positive pressure systems) or ingress of ambient air (in negative pressure system) are contingencies to be accounted for, in the hazardous area classification process. Lastly, it is worth keeping in mind that bulk dusts always retain some amount of air in the interstitial spaces between particles, so the operation of adding a bag of bulk material into an inerted vessel or container causes oxygen to enter the volume and affect the inerted system, albeit locally.

3.10 Zoning layouts are enough

It often happens that, when requested to provide the existing Hazardous Area Classification, a plant will present only the zoning layouts. While drawings are an effective visual aid to understand hazardous zone, here's a brief overview of what drawings will not do:

- Describe the plant, the process conditions and the operating procedures that existed at the time the zoning was made;
- Justify all the assumptions made, and the applied standards and regulations;
- Define physical and chemical characteristics of the flammable materials involved;

- Illustrate ventilation efficiency and reliability, as well as inerting systems, or discuss the housekeeping levels.

All of the above are included in the hazardous area classification report, which is an integral part of the risk assessment documentation of a plant and should not be overlooked or considered of lesser importance compared to the layouts.

4. Conclusions

When performing Hazardous Area Classification, which is the first step of Dust Hazard Analysis, determination and collection of flammability data and chemical-physical properties of the dust is of the utmost importance since the behavior of fires and explosions generated from a cloud of dust could be significantly affected by some operating conditions like temperature, humidity, and particle size. In order to avoid errors which could lead to overestimating or underestimating the risk, the assessment should consider normal and abnormal operations (e.g., maintenance, start-up and shut-down conditions), together with the possibility of having a failure of the inerting system, if present (i.e., evaluating the reliability of the system as a whole, including instruments and sensors). Furthermore, the internal volumes of the equipment handling the dust should also be subjected to the HAC assessment, considering the actual plant configuration, avoiding copying and pasting information from similar plants.

Abbreviations

DHA	Dust Hazard Analysis	LOC	Limiting Oxygen Concentration
HAC	Hazardous Area Classification	MEC	Minimum Explosible Concentration
K _{st}	Deflagration Index	MIE	Minimum Ignition Energy
LFL	Lower Flammability Limit	MIT	Minimum Ignition Temperature
LIT	Layer Ignition Temperature	P _{max}	Maximum Explosion Pressure

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