Dust Explosions - Hazardous Area Classification - Powder Handling Areas

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In the pharmaceutical, fine chemical, food and other process industries powders capable of generating an explosive dust cloud are commonly charged to process vessels either directly by hand or by using some form of mechanical assistance. This charging process is usually accompanied with some form of extract ventilation or containment.

EN 60079 Part 10-2 Classification of areas – Combustible dust atmospheres requires that the dispersion of the powder is taken into consideration as part of the hazardous area classification exercise without offering any suggestion of how to calculate or model this. The lack of scientifically derived data has led to frequent conflicts between designers and clients. Designers are rightly cautious and frequently classify the inside of the vessel Zone 21 or Zone 20. Users tend to argue that they have been operating these areas as safe areas for many years without problems. Are the designers being over cautious or are the users taking unnecessary risks?

To answer this question the authors carried out a literature search that provided sufficient information to allow a further understanding of the problems to be gained and a simple calculation method to be developed that indicate that designers are right to be cautious and that more information is required before it will be possible to allow more areas to classified as Zone 22 or as a safe area. A project is now in hand to investigate the issues in greater depth. The scope of the problem, the results from the simple calculation method, along with comparisons with EN60079 Part 10-2 are presented in this paper

Introduction

Many companies within the chemical and process industries use and manufacture a wide range of dusts that are combustible. These combustible dusts are capable of forming a potentially explosive atmosphere when dispersed in air or alternative oxidant. EU Directive 1999/92/EC, the ATEX 137 Directive and the transposed legislation in EU Member States requires that a Hazards Area Classification be carried out. The classification is carried using a number of recognised standards including EN 60079-10-2.

Hazardous Area Classification is not always a clear cut exercise and as will become clear from the discussion below some solids handling process have a high level of uncertainty within the classification process. Therefore, it is common for an operating company to have been carrying out a process for some time without recognising that potentially explosive dust clouds are being created as part of their process. In turn this has led to areas being classified as safe areas instead of hazardous areas and the companies have not been taking the required precautions.

On the other hand during the design phase for a new plant it is common for the design team to take a precautionary approach in light of this high level of uncertainty and classify areas as hazardous zones when their client has in the past classified them as safe areas. It is easy to see that this lack of certainty is leading to conflict between plant designers and their clients and to sub-optimal designs being created.

The purpose of the paper is to help to reduce the uncertainty in the classification process.

Explosion Pentagon

One useful way to explore the possibility of an explosion occurring is to consider the explosion pentagon. This takes the classic fire triangle and adds dispersion and confinement as two further conditions that need to exist before an explosion can occur. This shows the minimum requirements for a dust explosion

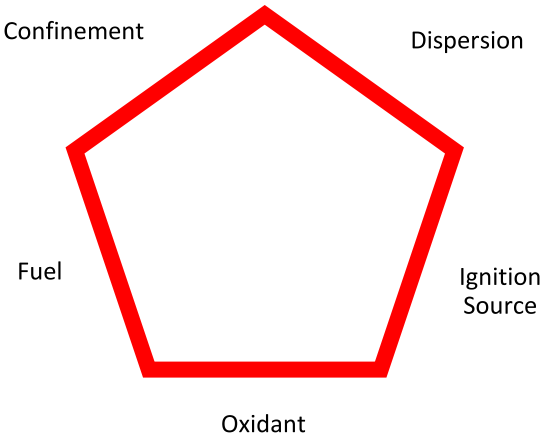


Figure 1 - Dust Explosion Pentagon

Fuel

In the case of the explosions being considered in this paper, the fuel will be provided by the combustible dust being handled in the process.

Oxidant

Any oxidant can cause an explosion and not just air/oxygen. However, for the purpose of this paper the oxidant of interest is air. This normally exists inside/outside the processing equipment unless specific measures are taken to eliminate it.

Dispersion

Unlike the dispersion of gases, evaporating liquids and flashing liquids, dusts require some mechanical energy to distribute them. One of the most important dispersion mechanisms for dusts is as a result of a small explosion. Intensive mechanical energy, which is integral to many processes such as pneumatic conveying, milling and fluidisation is also an important dispersion mechanism

Other processes such a pouring and tipping can also lead to dispersion of the dust.

Source of Ignition

There are many potential sources of ignition that have sufficient energy to ignite a combustible dust. However, consideration of sources of ignition is outside the scope of this paper.

Confinement

Confinement is frequently a natural part of the processes carried out in the process industries. The only time where confinement is not a natural part of the process is when operations such as tipping take place outdoors.

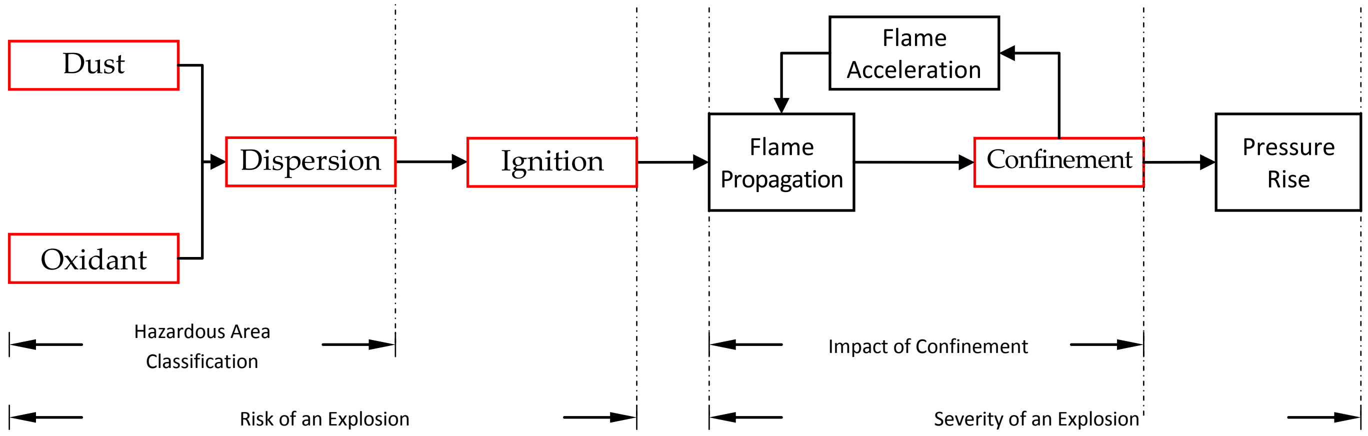


Figure 2 - Overview of dust explosion progression resulting from "unwrapping" the dust explosion pentagon.

Hazardous Area Classification

Unwrapping the Dust Explosion Pentagon

Cloney et al [5] suggest that unwrapping the pentagon provides a good way to understand the progress of a dust explosion. Also this approach results in a better understanding of the relationship between the explosion pentagon and hazardous area classification.

It is clear that hazardous area classification is related to the creation of potentially explosive atmospheres resulting from dispersion of a fuel (combustible dust) in the oxidant (air in this case). A dust cloud becomes potentially explosive when the concentration of dust exceeds the minimum explosive concentration (MEC) for the material in question (usually in the range 30 to 60 g/m^3).

Hazardous Zones

In EN 67009 Part 10-2 areas where potentially explosive dusts clouds may be generated are divided into three zones, Zone 20, Zone 21 and Zone 22.

These zones are defined by the standard in the following way:

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

"A place in which an explosive dust atmosphere, in the form of a cloud of dust in air, is not likely to occur in normal operation but, if it does occur, will persist for a short period only."

From the point of view of both designers and users it is of significant benefit to be able to decide whether one of more of these exist for the process and equipment in question and to understand how big these zones are.

Degree of Ventilation

EN 67009 Part 10-2 is a much less developed standard than its gas equivalent EN 67009 Part 10-1. In the latter standard the classification of zones takes into account the degree of ventilation and the availability of that ventilation. This means that in the case of a continuously present explosive gas atmosphere the area can be considered to be non-hazardous in the presence of a high degree of ventilation with good availability.

The degree of ventilation is obviously relevant to the formulation of an explosive dust atmosphere both in a negative and positive manner. Low velocity ventilation could lead to rapid reduction in dust concentration. On the other hand high velocity ventilation could cause dust layers to be lofted into the air stream and create an explosive atmosphere.

Dust Settling

Another difference between dusts and gases is the tendency for dust particles to settle out in still air. As discussed below the experimental evidence is that this happens very quickly for all but powders in the highest dustiness groups. So that once the dispersion mechanism is removed the concentration of a dust cloud falls very rapidly and it is very soon outside the combustion concentration.

However dust settlement creates additional problems where good housekeeping is not practised. It is possible for small dust explosions (usually referred to as primary explosions) to cause layers of settled powder to be lofted leading to a larger secondary explosion. This is a well-known phenomenon and must be examined as part of the hazardous area classification.

Dispersion

The dispersion of a dust depends on two factors, the propensity of the material being handled to form a potentially explosive dust cloud and the intensity of the mechanical energy being put into the process.

Propensity to Form a Potential Explosive Dust Cloud

This depends on three factors. Firstly the Minimum Explosive Concentration (MEC); the lower the MEC the more likely it is that a potentially explosive atmosphere will form. The MEC is a function of the material being handled, and also the particle size of the dust and the moisture content of the dust.

The second factor is the dustiness of the material. Some materials tend to clump together and form aggregates that make the apparent particle size greater and reduce the dustiness. On the other hand dusts with a small particle size that do not tend form aggregates will disperse more easily. Also important is the bond strength between the particles as discussed in Section 4.2 below.

The third factor is the settlement rate or stationery sinking rate of the particles. Hinds [11] proposed that the terminal velocity U reached by a spherical particle due to gravity can be estimated from a balance of forces.

$$U = \frac{\rho_p d_p^2 g}{18\mu} \qquad (1)$$

Where ρ_p and d_p are particle density and diameter respectively, g is the acceleration due gravity and μ is viscosity of air. So the settlement rate will depend on the particle density and the (apparent) particle size.

Mechanical Work Intensity

Eckhoff [7] suggests that a global dispersibility parameter D can be defined in the following way.

$$D = \frac{K}{W_{min}} \qquad (2)$$

Where W_{min} is the total minimum amount of work (energy) required to break all of the bonds in one unit mass of powder and K is dimensionless efficiency factor with a value between 0 and 1. K is a measure of how the work is applied to the powder being dispersed, which will be dependent on the type of mechanical process that is being carried out.

A simple modification to Equation 2 allows a better understanding of dispersibility.

$$D' = \frac{K' W_p}{W_{min}} \qquad (3)$$

Where K' is the efficiency of the mechanical process of transfer the work (energy) in the process in the work required to break the bonds and W_p is the work (energy) contained within the mechanical process. The outcome of Equation 3 can be seen in Figure 3

So for mechanical processes that involves a high level of mechanical work W_p and a high K' factor it is to be expected that the dust dispersion will be high. Conversely where the level of mechanical work W_p and/or K' is low, it is to be expected that much less dust would be dispersed.

Also for particles where W_{min} is low it is to be expected that the dispersion will be high whereas for particles with a high W_{min} the dust dispersion is expected to be low.

Eckhoff suggests that processes such as pouring powder into the top of a silo would have a higher K' value than airflows that may loft dust layers from a factory floor so that W_p for these air flows needs to be higher to achieve the same level of dispersibility.

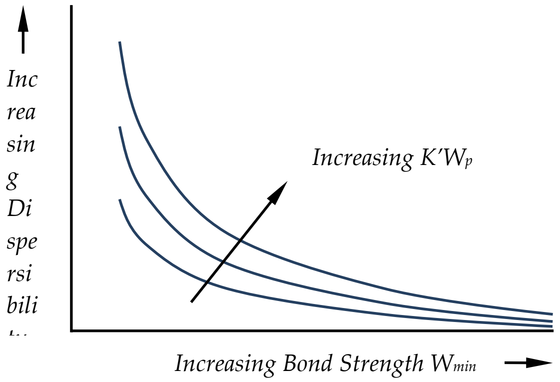


Figure 3 – Dispersibility Versus Bond Strength

Combined Propensity to Form a Potential Explosive Dust Cloud

Combining the factors discussed above leads to the conclusion that the propensity P_{exp} of a solids handling process to form an explosive dust cloud can be expressed as follows.

$$P_{exp} = f\left(\frac{1}{MEC}, D', \frac{1}{U}\right) \ldots\ldots\ldots(4)$$

Solids Handling Processes

Processes Where The Hazardous Area Classification Is Not Contentious

High P_{exp} Processes

There are many solids handling processes where P_{exp} is high, mainly because W_p is high. This includes process such as continuous conveying, milling, blending and fluid bed drying. In this case, it is current practice to consider that a dust cloud exists in some or all parts of the equipment that has a concentration greater than the MEC and therefore to classify the inside of equipment as Zone 20 or Zone 21 depending on whether the dispersion process occurs continuously or only occurs intermittent.

Low P_{exp} Processes

There are also some powder handling processes where practical experience shows that P_{exp} will be low. This is because D' is low, because W_{min} is high or because K'W_p is low.

This includes processes such as moving powder on a conveyor or tray drying (but not the discharge of this conveyer or the trays).

Uncertainty Leading to Sub-Optimal Designs and Conflict

Between the processes that clearly have a high P_{exp} and those that clearly have a low P_{exp} is a grey area of processes where is not clear whether a potentially explosive atmosphere will be created by the process.

Examples of these processes include many tipping and pouring operations encountered in the process industries, particularly in the fine chemical, pharmaceutical and food sectors, which involve low to medium W_p and a correspondingly low P_{exp}.

On top of this the quantity of material used is frequently low, so that the activity that is leading to dispersion of the dust is short lived.

Typical Problem Processes

Dispensing

Dispensing involves accurately measuring the required quantity of a starting material/ingredient for a formulation/reaction mixture and then adding that material into the process. In the case of solids this frequently involves transferring powder from some form of intermediate bulk container into a weigh container either by hand or by some form of conveying system. The quantities involved are often small, from grams to several kilogrammes. For most materials some dust extraction will be required to protect the operator making the manual additions.

The operation is usually slow because it is necessary to add the powder in a controlled manner. In the case of pharmaceuticals it is also necessary to minimise the formation of dust clouds to prevent cross contamination.

For materials that have a very low operator exposure standard (in the ng/m^3 to µg/m^3 range) the dispensing can take place into a fully contained glove box with an extraction system.

In some cases the dispensed material is transferred from the weighing container into a transport container. This action is similar to the pouring activity described below.

Pouring

Once dispensed it is necessary to pour the dispensed material into the processing vessel. This may be achieved via an open connection with local extract ventilation, via an extracted tip station as described below or by connecting the weighing/transport container directly to the processing vessel. In each case the rate of pouring is not usually controlled and the weighing/transport container is emptied as quickly as is reasonably practicable.

One recent development has been to make use of specially shaped single use plastic bags complete with clamp type hygienic coupling and a simple plastic clamp type valve on weighing and transport container and connect this directly to the process vessel. The container can then be simply discharged by inverting it and shaking the bag.

Tipping

Tip stations complete with extract ventilation can be connected onto processing vessels or intermediate hoppers and used to allow rapid tipping of the contents of either the weighing/transport container or from containers that have come directly from the material supplier (whether an internal or external supplier). These can be bags (circa 20 kg), kegs (up to 100 kg) or drums (up to 200 kg).

The prime purpose of the tip station is to allow the contents of the container to be tipped into the receiving vessel as quickly as possible without too much manual effort and to provide protection for the operators from the dust.

Spillage

The dispensing, pouring and tipping operations described are the intended operations but these are manual handling operations that often involve the use of containers that are awkward to handle and the probability of spillage occurring is high.

Dispersiblity

A search of literature shows that considerable amount on work has been done on dispersibility although it is usually referred to as dustiness of materials.

The majority of this work has focused on the requirements of occupational health rather than the risk of dust explosions.

Occupational Health versus Potentially Explosive Atmospheres

The primary consideration in the design of most pouring and tipping operations is occupational health relating to the occupational exposure standard (OES) of the material being handled. For a nuisance dust the OES would be 10 mg/m^3 whereas for some pharmaceutical active ingredients the OES could be measured in ng/m^3. Also the studies carried out for occupational health are particularly focused on understanding the respirable, thoracic and inhalable fractions within the dispersed dust.

By way of comparison the MEC for a typical material would be in the range of 30 to 60 g/m^3. This means that the MEC is at least three orders of magnitude greater than the OES of a nuisance dust and nine orders of magnitude greater than the OES for some pharmaceutical active ingredients.

With such a large difference between the OES and MEC it is to be expected that during the normal operation of a correctly designed solids handling it is very unlikely that a potential explosive atmosphere will exist outside the extracted or contained region. The only reason that such an atmosphere should exist outside these areas is due to spillage or leakage.

Dustiness Measurement

Dustiness is a property of a powder and is a surrogate method of measuring the work required to break particle bonds W_{min}. The literature indicates that there are many ways to measure dustiness. Hamelmann [8] presented a review in 2003. However, most of the methods of the dustiness measurement have been designed to provide data for occupational health studies and not dust explosions.

Three test methods stand out as being appropriate. Higman [10] presents the following relationship between test methods and industrial processes.

	Impact Tests	Rolling Drum	Fluidised Bed
Dustiness Ranking	2	2	2
Effectiveness of dedusting	1	2	2
Effects of attrition	0	1	1
Dust generation in			
Screening-classification	1	1	2
Mixing, granulation, coating	0	2	2
Pneumatic drying, conveying	0	2	2
Loading – unloading	2	1	1
Mechanical conveying – elevating	1	2	1
Bagging	2	1	2
Vehicle Movement	2	2	2
Losses from stockpiles	1	1	2

0 indicates unsatisfactory results,

1 indicates that reasonable results should be obtained with care and,

2 indicates that good results can be obtained.

Table 1- Dustiness test methods versus industrial process

Not only do the dustiness test methods need to be matched to the industrial process but it needs to borne in mind that the test methods do not provide good agreement either. Pensis et al [15] reviewed dustiness testing using the methods in EN 15051, 2006, which include two test methods, a continuous drop test (impact test) and a rotating drop test. They concluded that there is almost no agreement in classification achieved by the two dustiness methods.

Schneider [17] when comparing a single-drop impact test method with a rotation drum test found that the single drop produced between 1.5% and 45% of the dust produced by the rotating drum depending on the powder tested.

A test rig developed by Boundy et al [4] produced some interesting results but it had been specifically designed to produce results using a small sample and used a dispersion nozzle that provided a high W_p.

Impact of Particle Size and Specific Surface Area

It may be expected that the dustiness of a material with a small particle size would be greater than that for a large particle size. However Pensis et al [15] found that below 100 µm the dustiness increased with particle size and not the reverse. This is probably due to the agglomeration of particles as has been reported elsewhere.

They also reported that dustiness decreased with increasing specific surface area.

Drop Testing (Impact Testing)

For dispensing, pouring, tipping and spillage drop testing seems to be the most appropriate test method for dustiness.

One such standardised test is the VDI 2263 Part 9 test method described by Hauert [9]. This provides a dustiness coefficient Si that can be used to place materials in dustiness classes.

$$S_i = \frac{m^3/g}{t_f + t_s} \cdot \int_0^{t_f + t_s} c(t)dt \ldots\ldots(5)$$

Where m and g are units of length and mass, respectively and c(t) is the dust concentration measured in a container of the measuring system over time. t_s is the sedimentation time of 350 seconds and t_f is the conveying (powder feed) time of 300 seconds.

Unfortunately it is not clear how this test method can be used in relation to the problem of hazardous area classification and the MEC which is measured in g/m^3.

Work by Kippel et al [12] use a similar drop test method to measure dustiness and they present their information in g/m^3, making it more useful for the purpose of this paper. Their experimental rig consisted of a vertical cylinder 300 mm in diameter with a volume of approximately 75 litres. They injected a sample at the top of the cylinder using 2 barg air to gain a theoretical concentration of 250 g/m^3.

They used the following dusts:

Dust	Dustiness Group[1]	Particle Size µm		
		Median	d_{10}	d_{90}
Wheat Flour	1	65.4	11.7	163.3
Wood	2	260.3	76.4	649.5
Skimmed Milk Powder	3	45.4	11.5	98.8
Maize Starch	4	13.5	7.6	22.3
Lignite	6	37.7	3.8	230.5
Potato Starch	6	45.7	23.2	80.7

1 = Dustiness measured by VDI 2263 Part 9 method

Table 2- Dusts used by Kippel et al

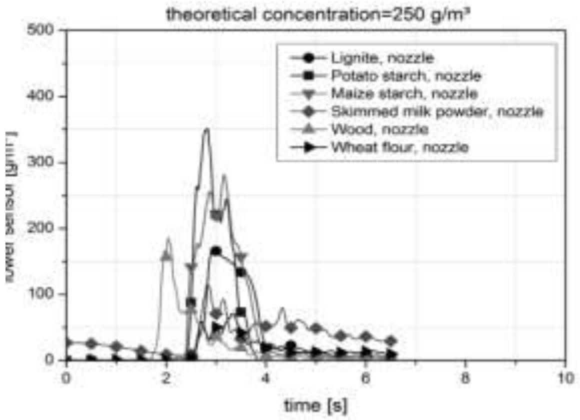
The dust concentration was measured at two positions roughly one third and two thirds up the cylinder. The results for the concentration at the lower sensor are presented in Figure 4

The dust concentration is largely in line with the dustiness group but not completely so. Notably the maize starch has as a higher concentration than lignite.

Due to the high W_p for this experiment the dust concentrations are not representative of the pouring and tipping operations being considered. However, it is of relevance to note that the rate at which the concentration falls and also that the skimmed milk powder (Dustiness Group 3) has the highest concentration at the end of the test.

It is clear from this work that the concentration of dust in a vessel falls rapidly once the flow of material stops.

Figure 4 - Dust concentration as a function of time.



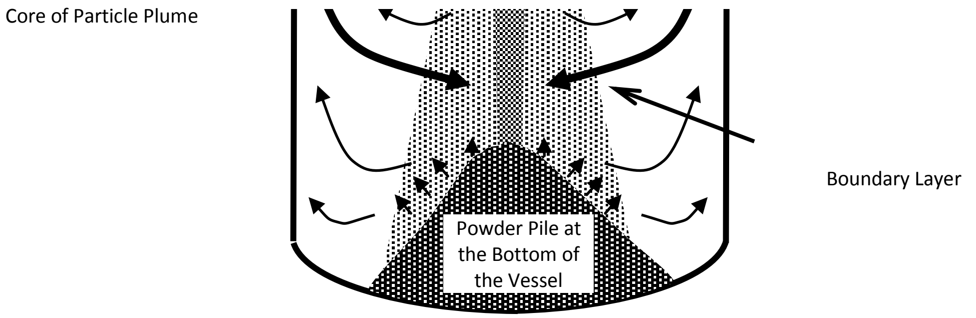


Figure 5 - Dust dispersion from a falling stream of material

Dust Dispersion Mechanisms

It is clear from the discussion above that although drop testing provides some useful information on dustiness it does not provide information directly usable for hazardous area classification and further consideration of the dust dispersion mechanism is required.

Cooper [6] suggests that for the dispensing, pouring and tipping operations under consideration there are two principal mechanisms for separating the dust from the bulk of the material that result from the air currents. Firstly, dust is liberated during the fall of the bulk material and secondly the falling material impacts on the powder pile releasing entrained air which causes pulvation of fugitive dust from the powder pile. This results in a "splash" of dust being generated. These physical mechanisms are illustrated in Figure 5.

Ansart et al [3] carried out a series of experiments with a free falling powder stream being discharged through a 5 mm diameter orifice. The powder used for this study was silica gel with a particle density of 1000 kg/m^3 and a loose poured bulk density of 535 kg/m^3. The particle size was d_{10} = 34µm, d_{50} = 60µm and d_{90} = 97µm.

The study includes drop heights of up to 1070 mm and considers a cone where the boundary layer as shown in Figure 5 contains 83% of the material that flow through the nozzle. At a height of 1070 mm the cone has a radius of 50 mm.

The results of the study are presented in a number of ways but the particle volume fraction (ϕ) versus radius of the cone at different heights is the most relevant to the paper. This information is based on a simulation developed from the experiment work. Figure 6 shows the volume fractions derived.

$$\varphi = \frac{Q_m}{\rho_p Q_{yp}} \ldots\ldots\ldots\ldots (6)$$

Where Q_m is the volumetric flow of the powdered material, Q_{yp} is the volumetric flow rate of the powder and the entrained air and ρ_p is the particle density. Since the particle density is 1000 kg/m^3 a particle volume fraction of 0.1% equates to approximately 1000 g/m^3.

There are two other important points to note from this study. Firstly, if 83% of the mass of the material flowing is within the cone then 17% material becomes dust outside the cone.

Secondly this study only considered the dust dispersed by the falling stream and did not consider any dust created by pulvation when the falling material hits the powder pile at the bottom of the fall.

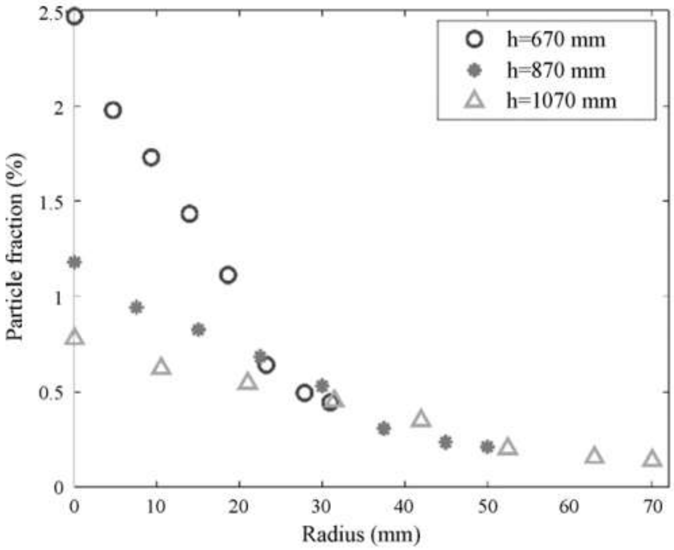


Figure 6 - Particle volume fraction version cone radius

Relevance to Hazardous Area Classification

Dispensing and Pouring

Dust Cloud Generation

The study by Ansart et al indicates that any free falling stream of powder is likely to generate a dust cloud that includes a region that falls above the typical MEC of combustible dusts. Within the boundary layer cone it will be in the order of 1000 g/m^3 or greater. However, that cone only extends by a small amount, the study indicates a cone angle of 6.3%.

The surprising figure is the 17% that forms a dust cloud. Plinke et al [15] carried out a study similar to Ansart et al but using a filtration system to measure the dust generated. They tested four materials, limestone, titanium dioxide, glass beads and lactose with a similar size range as the silica used by Ansart et al. They show dust generation in range 0.5% to 3% of the mass of material falling. It is possible that the study by Plinke et al is understating the dust generated because the filtration collection system did not collect all of the dust generated because it had settled out before reaching the filter.

The 17% is also surprising because the dust concentration implied would be high enough to be visible and it is to be expected that the boundary layer would be larger than stated in the paper.

To put these percentages into the context of hazards area classification it is worth carrying out a simple calculation. If 2.5, 5.0 and 10.0 kg of powder were charged to a 1 m^3 vessel and these were to form a homogeneous mixture in the vessel the following dust concentrations would be created.

Mass of Solid Charge kg	Percentage Dust Generation		
	0.5	3.0	17.0
2.5	12.5	75.0	425.0
5.0	25.0	150.0	850.0
10.0	50.0	300.0	1700.0

Table 3- Dust Concentration in kg/m^3 for a mass solid charged to a 1 m^3 vessel

The interesting point about this calculation is that with exception of 2.5 kg charged with 0.5% dust generation rate all the other results are within the range or close to being within the range MEC for most materials. On the basis of this simple calculation it is not important whether the work by Ansart et al or Plinke et al is more representation of the actual situation since both studies indicate that the MEC is likely to be exceeded.

This indicates that for the current level of knowledge, the only safe assumption is that when pouring a powder into the vessel that the MEC will be exceed in some part or the whole of the vessel. Without further study it is not safe to assume that the process will not create a dust concentration greater than the MEC unless only small quantities of a dust free powder are poured into a vessel. This conclusion is in-line with the recommendations in EN 60079-10-2

Dust Cloud Dissipation

The rate of dust cloud dissipation is relevant to the decision whether the inside of the vessel should be classified as Zone 20, 21 or 22. Clearly whilst any powder is being charged to the vessel a potential explosive atmosphere is likely to exist. If the powder is charged continuously or frequently then the inside of the vessel should be classified as Zone 20.

If the powder is not charged frequently then the inside of the vessel can be classified as Zone 21. Although the work by Klippel et al [13] indicates that the dust cloud is likely to dissipate rapidly it is not possible to classify the inside of the vessel as Zone 22 because the current indications are that an explosive dust atmosphere is likely to always occur in normal operation and not only as a result of rarely occurring mal-operation.

To allow the inside of vessel to classified as Zone 22 requires more studies to be carried out, possibly using computational fluid dynamics (CFD), to gain a greater understanding of the generation of dust clouds and whether any situation exists where the assumption that an explosive dust atmosphere will be created in normal operation can be replaced by confirmation that an explosive dust atmosphere would only be created by a rarely occurring mal-operation.

Spillage

The dust concentrations presented in Table 3 imply that a spillage of a similar quantity of powder would also create an explosive dust cloud. However, the rate of dissipation indicated by Klippel et al would suggest that such a dust cloud would persist for only a short period and therefore it is reasonable to classify an area subject to possible spillage as a Zone 22.

The concentrations presented in Table 3 also give a simple indication of the potential size of the zone. However, in this case the percentage dust generation rate is much more important as this has a direct impact on the size of the zone. It is clear that further work is required to understand how big a Zone 22 would be and how dustiness impacts on the size of the zone. The level of ventilation associated with the Zone 22 will also be important.

Sack Tip Station

EN 60079-10-2 recommends that the inside of a sack tip station is classified as Zone 20. Based on the discussion above this is the correct classification.

The simplest assumption is that this Zone 20 extends throughout the dust extraction system as far as the dust collection filter, but is possible that CFD may demonstrate that this is unnecessarily cautious.

The EN standard recommends that the outside of an extracted sack tip station is classified as Zone 22. However, it does not define the size. This sizing needs to be based on the process and the dustiness of the powders handled and is an area for further work. This is an area where the level of ventilation will be important.

In the case of a sack tip station with no extract a Zone 21 is recommended by the standard; again without any sizing. Studies on dustiness and CFD would help with sizing such a zone.

Conclusions

Considerable work has been carried by a number of researchers covering the dustiness of powders and dispersion of dust. Some of this is relevant to hazardous area classification.

Two of the studies indicate the rate of generation of dust in terms of the mass of dust dispersed compared to the mass of material in a free falling stream. This rate of generation varies from 0.5% to 17% depending on the powder studied and the experimental method. However, a simple calculation indicates that recommendations given in EN 60079-10-2 for the inside of equipment are consistent with these studies.

It is possible that smaller quantities of materials with a low dustiness may not create an explosive dust atmosphere but further work is required to demonstrate whether such a situation exists.

The sizing of a Zone 21 or Zone 22 outside of equipment remains more of a problem. The dustiness of a powder has a large impact on this and a better understanding of the rate of generation of dust is required. The zone size implied by a dust generation rate of 0.5% is considerably different than that implied by a rate of 17%. It is likely that CFD studies will be required to supplement the data on dust generation rates.

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