

Australian/New Zealand Standard™

Code of practice for handling combustible dusts



AS/NZS 4745:2012

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Australian Paint Manufacturers Federation
Australian Petroleum Production and Exploration Association
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Australian/New Zealand Standard™

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PREFACE

This Standard was prepared by the Joint Standards Australia/Standards New Zealand Committee MS-011, Classification of Hazardous Areas, with the assistance of the Joint Subcommittee MS-011-01, Combustible Dusts, to supersede AS/NZS 4745:2004.

This Standard incorporates Amendment No. 1 (June 2013). The changes required by the Amendment are indicated in the text by a marginal bar and amendment number against the clause, note, table, figure or part thereof affected.

This Standard is intended to assist those industries which may have risks associated with the presence of combustible dusts as part of their process, in minimizing the risk of injury, death or loss of property to fire and/or explosion. It sets out good design and management principles and practices for the construction, operation and maintenance of manufacturing and processing plants and associated transportation and storage systems.

The objective of this revision is to update the referenced documents and bring the Standard into line with current editorial practices. This revision also modifies the classification for levels of protection in Section 7 to align with the classifications used in referenced Standards.

The technical content of this Standard is based on but not equivalent to EN 1127-1, *Explosive Atmospheres—Explosion-prevention and Protection, Part 1: Basic Concepts and Methodology*.

The term ‘informative’ has been used in this Standard to define the application of the appendix to which it applies. An ‘informative’ appendix is only for information and guidance.

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Australian/New Zealand Standard **Code of practice for handling combustible dusts**

SECTION 1 SCOPE AND GENERAL

1.1 SCOPE

This Code of Practice is intended to apply whenever combustible dusts are encountered in quantities sufficient to give rise to a fire and/or explosion. This would normally include, but is not limited to, manufacturing plants and processes (where dusts may be generated or used as part of the process) and bulk storage and handling installations.

It provides a means by which relevant parties can firstly determine whether or not risks exist within an existing or a proposed system or facility, secondly ascertain the nature of such risks, and thirdly determine the means by which the criteria for safe design, construction, operation and maintenance can be met.

The Code is not intended to apply to parts of pulverized fuel combustion systems, or other systems where burning is intended. Where other applicable Standards and Codes exist for the design, construction, operation and maintenance of those systems, they may be adopted.

1.2 APPLICATION

The people who should use this Standard will specifically include those listed below, but this list is not meant to be exhaustive and the Standard may well be relevant to others not listed. Anyone in doubt should make their own enquiries as to the relevance of the Standard to their industry or specific circumstances.

Interested and affected groups include—

- (a) designers;
- (b) equipment manufacturers and suppliers;
- (c) installers of plants;
- (d) plant owners and operators;
- (e) employees;
- (f) storage and transport operators;
- (g) inspectors;
- (h) insurance companies; and
- (i) training providers.

1.3 REFERENCED DOCUMENTS

The following documents are referred to in this Standard.

NOTE: Bibliographic references are listed in Appendix B.

AS

- 1674 Safety in welding and allied processes
1674.1 Part 1: Fire precautions

AS/NZS

- 1020 The control of undesirable static electricity
1768 Lightning protection
2865 Safe working in a confined space
3931 Risk analysis of technological systems—Application guide
4804 Occupation health and safety management systems—General guidelines on principles, systems and supporting techniques
60079 Explosive atmospheres
60079.10.2 Part 10.2: Classification of areas—Combustible dust atmospheres
60079.14 Part 14: Electrical installations design, selection and erection
60079.17 Part 17: Electrical installations inspection and maintenance
61241 Electrical apparatus for use in the presence of combustible dust
61241.2.1 Part 2.1: Test methods—Method for determining the minimum ignition temperature of dust
61241.2.2 Part 2.2: Test methods—Method for determining the electrical resistivity of dust in layers
61241.2.3 Part 2.3: Test methods—Method for determining the minimum ignition energy of dust/air mixtures

AS/NZS ISO

- 31000 Risk management—Principles and guidelines

ISO

- 6184 Explosion protection systems
6184-1 Part 1: Determination of explosion indices of combustible dusts in air

NFPA

- 68 Guide for Venting of Deflagrations
69 Standard on Explosion Prevention Systems

VDI

- 2263 Dust fires and dust explosions; hazards, assessment, protective measures
3673.1 Sheet 1 Pressure venting of dust explosions

1.4 DEFINITIONS

For the purpose of this Standard definitions presented in the Glossary at the end of the document apply.

SECTION 2 OHS AND RISK MANAGEMENT

2.1 OCCUPATIONAL HEALTH AND SAFETY MANAGEMENT SYSTEM

2.1.1 Awareness of regulations and responsibility

Responsibility for awareness of relevant legislation, standards, codes of practice etc. lies with the organization and responsible individuals within the organization.

Responsibilities are detailed in legislation, referenced Standards, Codes of Practice etc. (e.g. OHS Acts in Federal and State legislation, Australian and New Zealand Standards, WorkCover/OHS Guidelines and Codes of Practice).

2.1.2 Occupational health and safety legislation

In the Commonwealth of Australia and each state and territory and in New Zealand there exists a principal piece of Occupational Health and Safety Legislation (Act) that sets out the requirements necessary to establish and maintain safe and healthy workplaces. The Acts are generally supported by Regulations, which are more specific and prescriptive. In each case legislation provides a range of duties for each workplace participant.

It is the responsibility of all parties to identify the Acts and Regulations that may be applicable to the installation and apply the requirements of those Acts and Regulations accordingly.

Duties of designers, importers and other parties may also be specified in the relevant OHS Acts and Regulations.

Rights and duties, which are representative of employer's specific duties in Australian and New Zealand jurisdictions include the following:

- (a) Provision and maintenance of safe plant and systems of work.
- (b) Safe systems of work in connection with plant and substances.
- (c) A safe working environment and adequate welfare facilities.
- (d) Information and instruction on workplace hazards and supervision of employees in safe work.
- (e) Monitoring the health of their employees and related record keeping.
- (f) Employment of qualified persons to provide health and safety advice.
- (g) Nomination of a senior employer representative.
- (h) Monitoring conditions at any workplace under their control and management.

NOTE: See Appendix B [Ref. 1] for more information.

2.1.3 Duty of care

The presence of combustible dust in many processes presents a hazard to people, buildings, plant and the environment.

Legislation administered at all levels of government places a responsibility on organizations and individuals to exercise a duty of care when designing, constructing, installing, operating and maintaining buildings, plant and equipment to ensure the safety of their employees, contractors, customers and the general public as well as protection of the environment.

In this respect the duty of care usually includes—

- (a) ensuring that the process, plant or equipment is safe and without risks to health when properly used; and

- (b) providing, or arranging for the provision of, adequate information about the process, plant or equipment to the persons to whom it is supplied to ensure its safe use.

The implementation of an Occupational Health and Safety Management System (OHSMS) is a means of demonstrating an organization's compliance with the requirements of Occupational Health and Safety legislation and the evidence of due diligence provided by the existence of OHSMS may provide a basis for a defence when charged with an offence under Occupational Health and Safety legislation.

Reasons for implementation of an OHSMS by an organization may also include ethical, industrial relations and financial reasons, however, the principal reason should always be to achieve improvement in OHS performance in the organization.

In respect of designers or users (or their representatives) of plant and substances for use at work the duty of care usually includes providing, or arranging for the provision of, adequate information about the processed materials and the plant to which equipment is to be applied to suppliers of equipment to ensure its safe application.

2.1.4 Occupational health and safety management system model

The generally accepted model for OHSMS in Australia and New Zealand is described in AS/NZS 4804. This model describes five basic principles which when incorporated in an OHSMS will provide for improvement and maintenance of an organization's OHS performance.

The five principles as detailed in the Standard are:

- (a) Commitment and policy.
- (b) Planning.
- (c) Implementation.
- (d) Measurement and evaluation.
- (e) Review and improvement.

2.2 RISK MANAGEMENT STANDARDS

An important tool in any OHSMS for use in identifying and minimizing the effects of hazards, such as that which may arise for the presence of combustible dust, is risk management.

Standards Australia and Standards New Zealand have produced both generic Standards (AS/NZS ISO 31000) and technology specific Standards (AS/NZS 3931) setting out guidelines for risk management systems and describing the risk management process.

These Standards should be used both to establish an organization's risk management system, and as a basis for the management to a specific risks associated with combustible dusts.

2.3 TRAINING

To enable the risk management process to be effective organizations should ensure that adequate resources are allocated to the training of personnel.

Personnel employed in the various phases of the risk management process should be appropriately qualified and experienced in the methods employed in risk management and possess appropriate knowledge of the organization's processes and their specific risk management requirements.

2.4 RECORDS

The operation of the risk management system should be documented and records retained. Typically these records would include the following:

- (a) Identified hazards.
- (b) Controls.
- (c) Test and maintenance records.
- (d) Audits and corrective actions.
- (e) Training.

Records not only provide evidence of the existence and effective operation of the risk management system but also assign responsibility and accountability and provide ongoing information for monitoring of risks, particularly in the situation where there are changes to plant or personnel.

More detailed information is provided in AS/NZS ISO 31000, Clause 5.7.

SECTION 3 HAZARD ASSESSMENT

3.1 DUST CHARACTERIZATION

3.1.1 Introduction

Typical factors which are relevant to assessment of hazards associated with dusts are outlined below. Specific examples and other information are also provided to assist users in the assessment of hazards.

3.1.2 Chemical composition

3.1.2.1 General

There are two aspects to consider, namely the thermodynamics of the explosion, and the kinetics. The thermodynamics is concerned with the amount of heat that is liberated during combustion, the kinetics with the rate at which the heat is liberated. Dust chemistry influences both thermodynamics and kinetics, which are also to some extent coupled.

Dust explosions generally arise from rapid release of heat due to the chemical reaction:

fuel + oxygen → oxides + heat.

In some special cases metal dusts can also react exothermally with nitrogen or carbon dioxide, but most often oxidation by oxygen is the heat generating process in a dust explosion. This means that only materials that are not stable oxides can give rise to dust explosions. Substances that cannot give rise to dust explosions include silicates, sulphates, nitrates, carbonates and phosphates and therefore dust clouds of Portland cement, sand, limestone, etc. cannot give rise to dust explosions.

The materials that can give rise to dust explosions include the following:

- (a) Natural organic materials (grain, linen, sugar, etc.).
- (b) Synthetic organic materials (plastics, organic pigments, pesticides, etc.).
- (c) Coal and peat.
- (d) Metals (aluminium, magnesium, zinc, iron, etc.).

The heat of combustion of the material is an important parameter because it determines the amount of heat that can be liberated in the explosion.

3.1.2.2 The influence of composition on explosion characteristics

For explosible dusts, the chemical composition affects ignitability, the heat released in an explosion and the rate of rise of pressure during the explosion. For foodstuffs, carbohydrates exhibit a higher rate of pressure rise than proteins or fats, so for a fixed particle size distribution, the relative concentration of carbohydrate in the food will determine the level of hazard. For synthetic plastics, the presence of chlorine compounds will reduce the level of hazard.

3.1.2.3 Further information

Further information is contained in Appendix B [Ref. 2].

3.1.3 Moisture

For many organic dusts, moisture in the dust reduces both ignition sensitivity and explosion violence of dust clouds. Its specific role is complex. First, evaporation and heating of water represents an inert heat sink. Secondly, the water vapour mixes with the pyrolysis gases in the preheating zone of the combustion wave and makes the gas mixture less reactive. A third factor is that moisture increases the inter-particle cohesion of the dust and inhibits dispersion into primary particles.

It is normal practice to dry powder samples before testing their explosibility characteristics to ensure conservative test results.

Water, even in small amounts, can initiate thermal decomposition or microbiological self-heating in some products and also reacts with some metals to form hydrogen. Therefore moisture may in some instances increase ignition sensitivity and explosion violence.

3.1.4 Particle size distribution and shape (specific surface area)

The particle size distribution and shape of the particles determine the surface area available for reaction with the oxidizing atmosphere. These parameters vary with time and location within the plant.

There are many methods for determining the particle size distribution of granular solids, powders and dusts. These include sieving, laser diffraction and sedimentation. All the methods can provide the specific surface area for the material. In general, the severity of a dust explosion will increase with the specific surface area (e.g. smaller particle size).

The combustion rate has a clear dependence on particle size with combustion rate increasing as particle size reduces. This trend however, does not continue indefinitely. The limiting particle size below which the combustion rate of the dust cloud does not increase anymore, depends on the ratios between the time constants of the three consecutive processes, devolatilization, gas phase mixing and gas phase combustion. Particle size primarily influences the devolatilization rate. Therefore if the gas phase combustion is the slowest of the three steps, increasing the devolatilization rate by decreasing the particle size does not increase the overall combustion rate.

For coals and organic materials pyrolysis/devolatilization always precedes combustion, which primarily occurs in the homogeneous gas phase. For coals it was found that the limiting particle diameter is of the order of 50 μm . However for materials yielding gaseous pyrolysis products that are more reactive than volatiles from coal one would expect the limiting particle size to be smaller than for coal.

For natural organic compounds such as starch and protein, the limiting particle diameter is probably not much smaller than about 10 μm , whereas for reactive dusts such as organic dyes, it may be considerably smaller.

For metals, the limiting particle size, below which there is no longer any increase in ignition sensitivity and explosion violence, is considerably smaller than for most organic compounds. This is because these metals do not devolatilize or pyrolyse. Further information is given in Appendix B [Ref. 2, pp 5-6, 25-32, 487-488].

3.2 SAFETY CHARACTERISTICS OF DUSTS

Dusts can occur in processing plant as layers or as clouds.

Layers may be electrically conductive, thermally insulating or have a potential for self-heating or self-ignition. Layers of dust, when heated, may produce combustible gases which may mix with air and form explosive gas mixtures.

Dusts may contain combustible organic solvents (a hybrid mixture) which may affect the combustion behaviour.

The following conditions are necessary for dust combustion to occur:

- (a) Dust will be combustible.
- (b) Dust concentrations are within the flammable limits.
- (c) There is sufficient oxidant to support combustion.
- (d) The dust and the oxidant are mixed.

- (e) An ignition source strong enough to initiate combustion is present.

For the majority of materials in dust form the lower explosible limit is around 30 g/m³ to 40 g/m³. From experience this generally equates to a dust cloud giving approximately 2 m visibility.

3.3 COMBUSTION BEHAVIOUR

3.3.1 Smouldering

Smouldering is the slow combustion without flame either over the surface of a flat layer of dust or through the underlying volume. Smouldering at the surface is usually the result of ignition at the surface. Smouldering within the deposit is usually the result of an ignition source buried within the powder or a chemical reaction leading to ignition such as spontaneous heating. The smouldering propagates upwards until it reaches the surface.

Smouldering is a concern in the processing of powders as powders are relatively easy to ignite and a smouldering powder may suddenly develop into a rapidly spreading fire after a long period of quiescence.

For sustained smouldering a minimum depth of powder needs to be present. The smouldering rate of a given powder is governed by the particle diameter. Smouldering rates can be increased by the action of airflow.

NOTE: Palmer, Appendix B [Ref. 3] has recorded the smouldering characteristics of a number of powders.

3.3.2 Flaming combustion

A powder will burn with a flame if sufficient vapour is generated either as a product of combustion or as volatiles from the powder. The vapours may be generated by the heat transfer from the flame to the powder surface. Flames can penetrate a layer and propagate downwards and sideways among the particles if there is a sufficient void. Under these conditions the layer is likely to be completely involved in the fire relatively rapidly and the rate of heat generation is also rapid.

3.3.3 Exothermic decomposition

Some dusts will decompose in an oxygen deficient atmosphere if they are heated. The decomposition can spread throughout the product producing a high temperature rise and liberating substantial amounts of gas. The large amounts of gas produced can cause a pressure build-up in a closed vessel that may result in the rupture of an unprotected vessel.

3.3.4 Dust explosions

3.3.4.1 General

A dust explosion occurs when a fine dust suspended in an oxidizing environment such as air is ignited. This results in rapid flame propagation in combination with a rise in pressure. The rise in pressure is due to the expansion effect as a result of the heat released from the combustion and to the gases that may be evolved during combustion. The rise in pressure has an explosive force that is capable of damaging plant and buildings and injuring people. It is generally considered that a dust explosion is unlikely to be initiated by dust particles larger than 500 µm but once ignited larger particles will contribute to the propagation of the explosion.

3.3.4.2 Dust deflagration

A dust deflagration is an explosion where the flame speed is subsonic. Explosion pressures can be up to 13 bar gauge for this type of explosion for a single enclosed vessel and higher for interconnected vessels.

3.3.4.3 *Detonations*

A detonation is an explosion where the flame speed is supersonic and the flame front is accompanied by a shock wave. The damage is much greater than for a deflagration. Most dusts will not detonate in industrial plant. However, highly explosible dusts such as aluminium have been known to detonate in long ducts. Pressures can reach up to 30 bar gauge in a detonation.

3.3.4.4 *Primary and secondary explosions*

A primary explosion takes place within the confines of the equipment of the processing system. It will cause a rapid rise in pressure within the equipment in which it occurs. However, if the pressure is relieved into an adjacent vessel or external to the equipment into the work area, the pressure waves from this primary explosion will dislodge any powder deposited on the neighbouring surfaces and cause it to be thrown into suspension in the air creating a second turbulent dust cloud. The flame front following the pressure waves will then ignite the dust cloud causing a secondary explosion. The effects of the secondary explosion are often more severe than those of the primary explosion due to the larger ignition source and the turbulence created by the preceding pressure wave.

3.3.5 **Atmospheric influences**

Increasing process operating pressure generally increases the explosion pressure and may compromise inerting. Elevated process oxygen concentrations may increase the rate of pressure rise and the explosion pressure.

Higher process operating temperatures generally increase the explosion pressure and may increase the risk of self-ignition.

Process hybrid mixtures are a mixture of a combustible solid and a combustible vapour or gas and may have higher rates of pressure rise and maximum explosion pressures than those of the individual components. Hybrid mixtures may also have wider flammable ranges.

The relative humidity of the atmosphere in a dust cloud affects the explosion violence through the second, and sometimes the third factor described in Clause 3.1.3. High relative humidity also reduces the danger from electrostatic discharges.

3.3.6 **Gas release**

The products of combustion are deficient in oxygen and are also likely to contain toxic gases such as carbon monoxide. The concentration of the toxic gases may be sufficiently high for a few breaths to be fatal so that momentary unconsciousness due to the blast can result in death.

Another potential combustion risk occurs because many plants use nitrogen as an inerting agent to protect against explosion during normal working of the plant. The atmosphere after an explosion may be rich in the inerting agent and may pose an asphyxiation hazard to those entering the area.

3.4 **DETERMINATION OF DUST CHARACTERISTICS**

3.4.1 **General**

To sufficiently survey the potential danger of a dust, an engineer may not be able to avoid carrying out numerous laboratory tests that are based on standardized methods (see Appendix B [Ref. 4] for combustion and explosion characteristics of dusts). The results are known as safety characteristics. Depending on the effort spent, a more or less comprehensive picture will result. The scope of the tests has to be determined in close collaboration between the tester and user, working toward the solution to the problem.

Tests are made for both dust layers and dust suspensions, since these show different behaviour.

Safe operation involves transforming the safety characteristics into plant operations.

Figure 1 is an overview of the various test methods to be considered in the following sections.

Thorough knowledge of the ignition behaviour of dust/air mixtures with electrical sparks (MIE) and hot surfaces (MIT) is important for assessing the hazards in dust carrying plants. The ignition behaviour essentially sets the extent, and hence, the cost of the protective measures to be used. This is especially true for the prevention of ignition sources and for the understanding of the ignition phenomena regarding static electricity, e.g. brush discharges, bulk surface discharges, spark discharges, and propagating brush discharges.

Further information is given in Appendix B [Ref. 2] and [Ref. 5] and VDI 2263.

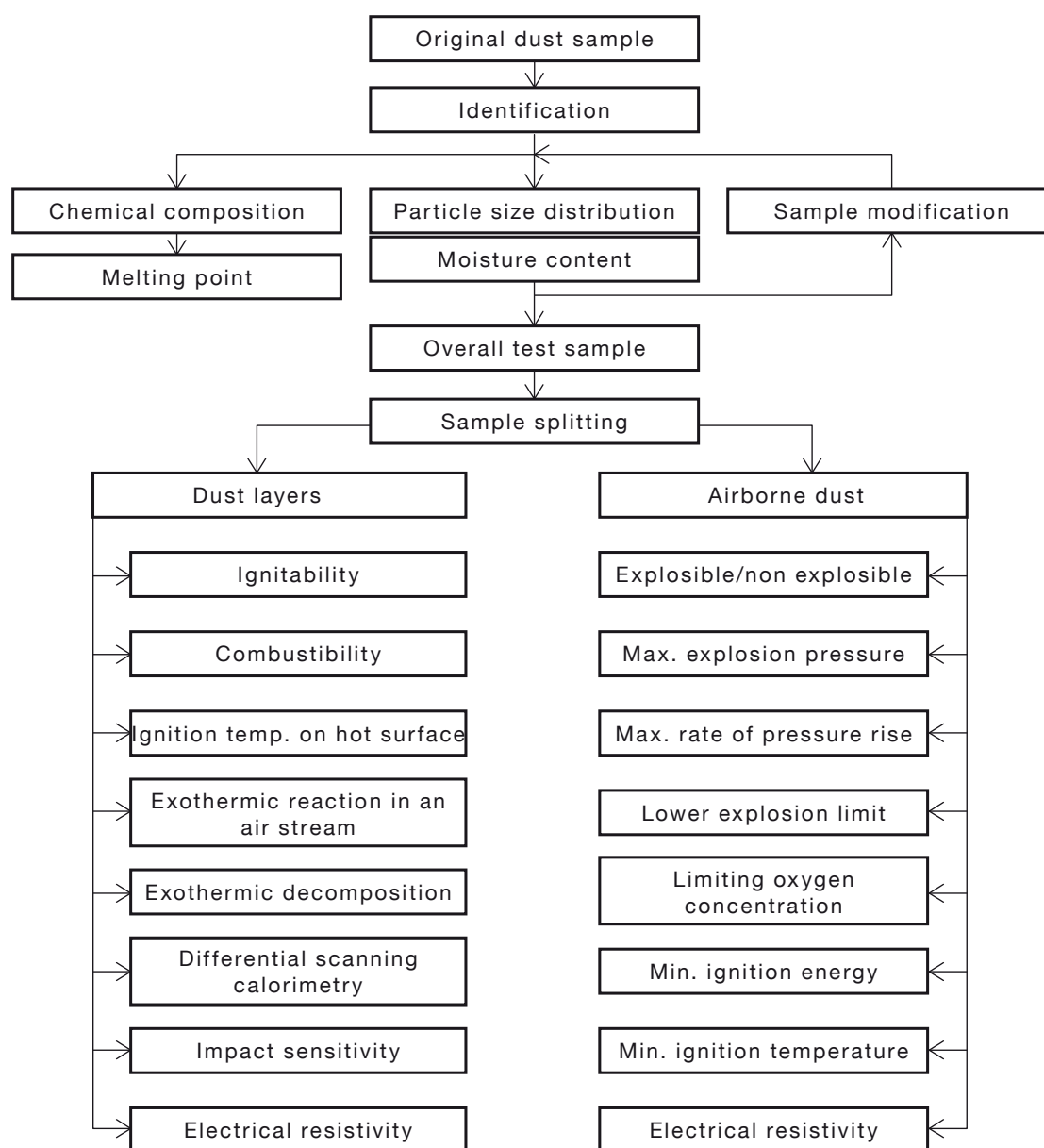


FIGURE 1 OVERVIEW OF TEST METHODS

3.4.2 Dust layers

3.4.2.1 Combustion rating

This test measures the ignitability and the combustibility of a dried product according to the following criteria:

- (a) Can the product be ignited at all?
- (b) Is the ignition propagated?
- (c) Is there a fire or a flameless reaction?

Testing is in accordance with VDI 2263.

The combustibility of the product is rated in accordance with the course of the reaction and characterized as a class number according to VDI 2263 (see Table 1). A temperature increase from 20°C to 100°C normally results in a change of the burning class (BC) from 1-3 to 4-6.

TABLE 1
TEST RESULTS DETERMINE THE BURNING CLASS
OF A POWDER LAYER

Test result		Class	Reference substance
No ignition	No spreading of fire	1	Table salt
Brief ignition, rapid extinction		2	Tartaric acid
Localized combustion or glowing with practically no spreading		3	D + lactose
Glowing without sparks (smouldering) or slow combustion without flames	Fire spreads	4	H – acid
Burning fireworks or slow, quiet burning with flames		5	Sulphur
Very rapid combustion with flame propagation or rapid decomposition without flame		6	Black powder

3.4.2.2 Minimum ignition temperature (glowing temperature)

The minimum ignition temperature (MIT) or glowing temperature describes the flammability behaviour of a flat dust layer on a hot surface. It is defined as the lowest temperature of a hot surface at which ignition occurs in a dust layer of specified thickness on this hot surface.

In the determination of the minimum ignition temperature for a layer of given thickness, repeated trials are carried out, using a fresh layer of dust each time and with up and down adjustments to the temperature of the heated surface until a temperature is found which is high enough to cause ignition in the layer but which is no more than 10 K higher than a temperature which fails to cause ignition.

Determining the MIT is described in AS/NZS 61241.2.1.

3.4.2.3 Exothermic reaction in an air stream (relative auto-ignition temperature)

This test determines the temperature of a powder in a hot air stream, in which an oxidation reaction occurs at a significant scale. The test is used for products that are subjected to elevated temperatures in an air stream for a short period, such as in a spray dryer. This test allows the dryers inlet temperature to be set.

The term auto-ignition means the ignition of combustible matter in air subjected to uniform heat. The temperature of the surrounding atmosphere (storage temperature) that initiates auto-ignition after self-heating of the product is called the auto-ignition temperature. Self-heating is caused by an already evident oxidation in air at the storage temperature. Such oxidation will liberate a certain amount of heat per unit time and mass. If the heat is not entirely transmitted to the surroundings, the product will heat up and auto-ignition may result.

Whether there will be self-heating or even auto-ignition depends upon the ratio of heat generation to heat transmission. The ambient temperature which will initiate the auto-ignition of a certain dust will therefore not only depend upon the type of dust (chemical nature, particle size, moisture content, etc.) but also on the storage mode, the shape and size of the pile, and the duration of heat exposure.

All statements for the auto-ignition temperature have to include the shape and size of the dust pile (method dependency), hence the term relative auto-ignition temperature.

The auto-ignition temperature is determined in accordance with VDI 2263. The test report gives the temperature at which the first exothermic reaction occurs for a given sample volume and time.

3.4.2.4 *Exothermic decomposition (oxygen lean conditions)*

Elevated temperature may cause a product to undergo a chemical transformation that will not require oxygen. The reaction may be endothermic or exothermic. The latter greatly affects safety, while the former may only affect operations or quality control.

Exothermic reactions may generate gases upon decomposition in a closed vessel. In addition these gases may be flammable. This could pose an additional explosion risk.

Determining exothermic decomposition involves measuring the lowest temperature that results in an exothermic reaction in a test tube under lean oxygen conditions (refer to VDI 2263). This test is made on products or reaction mixtures subjected to elevated temperatures over long periods, closed off from fresh air. Examples include reactors, and vacuum ovens and dryers.

3.4.2.5 *Exothermic decomposition under temperature controlled conditions*

A test sample and a reference sample (graphite) are heated in test tubes at a constant rate, up to a final oven temperature that depends upon the sample.

A linear plot of temperature vs. time will reveal a straight line for the graphite, and for the sample, a peak above this line will show an exothermic reaction. The onset temperature for this reaction is at the point at which the temperature–time exotherm rises above the line for graphite. At the same time, the flammability and quantity of the decomposition gases may be measured.

3.4.2.6 *Differential scanning calorimetry*

Differential scanning calorimetry can determine the onset temperature and quantify the total energy release of any exothermic reaction. It measures the rate at which heat should be transferred to or from the test sample in order to maintain it at the same temperature as an inert reference sample. The reference sample temperature is usually increased at a predetermined linear rate (constant temperature rise per unit time).

3.4.2.7 *Impact sensitivity*

For grinding processes and paddle dryers with bars, the sensitivity of a product to shock has to be found. A product is impact sensitive and explosible if it disintegrates with a bang upon its exposure to impact under given test conditions (refer to VDI 2263).

3.4.2.8 *Electrical resistivity*

The significance of electrical resistivity of powders and dusts in the context of process safety is dual. Firstly the chance that dusts will penetrate into electric and electronic equipment and give rise to short circuits and equipment failure increases as the dust resistivity decreases. Secondly, the possibility of accumulating hazardous electrostatic charges and voltages in an industrial process increases with increasing electrical resistivity powder.

The test method for determination of the electrical resistivity of powders is outlined in AS/NZS 61241.2.2.

A dust is considered conductive, and thus capable of short circuiting electrical and electronic equipment when admitted inside such equipment, if electrical resistivity $\Delta \leq 10^3 \Omega\text{m}$.

From an electrostatic point of view, dusts are considered to be conductors incapable of storing charge until their resistivity exceeds $10^9 \Omega\text{m}$.

Resistivity is not an absolute property of a powder, but depends strongly on its moisture content. Beyond the saturation point test methods are not reliable. This point varies from approximately 12% to 25% moisture depending on the type of material.

3.4.3 **Airborne dust/air mixtures—Deflagration parameters in a near spherical closed vessel (20 litre or greater)**

This method measures the deflagration parameters of a combustible dust/air mixture in a near spherical 20 litre or greater closed vessel (refer to ISO 6184-1). The parameters are the dust explosivity, lower explosion limit (LEL), maximum explosion overpressure P_{max} , maximum explosion constant K_{max} , and the limiting oxygen concentration (LOC).

The test uses chemical igniters as the ignition source. The ignition energy is 10 kJ, and the ignition delay time is 60 ms. The parameters measured are P_{max} and the maximum rate of pressure rise $(dp/dt)_{\text{max}}$. This provides information to predict the effects of an industrial scale deflagration of a dust/air mixture (see Figure 2).

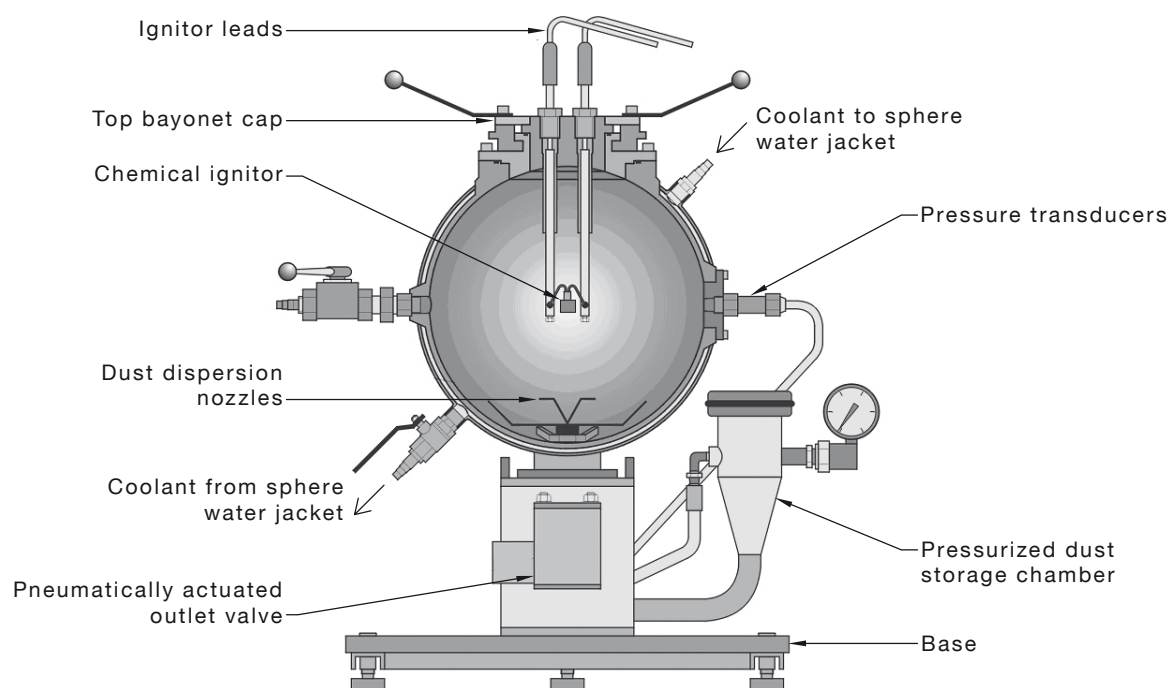


FIGURE 2 TEST FOR THE DEFLAGRATION PARAMETERS OF COMBUSTIBLE DUST/AIR MIXTURES

$P_{\max}$ when determined in closed, spherical, or cubic vessels of sufficient volume ($V \geq 20$ L) with a central ignition source, is practically independent of the volume of the vessel. But $(dp/dt)_{\max}$ does depend on the volume. It decreases with increasing volume; following the cubic law, $K_{\max}$ is dust and test specific, but independent of volume. The cubic law is applicable only for a volume $V \geq 20$ L.

The cubic law is—

$$V^{1/3} [m^3] \times (dp/dt)_{\max} [\text{bar/s}] = K_{\max} [\text{bar.m/s}]$$

The large number of dusts produced and handled in processing plants led to a classification of dusts, according to their $K_{\max}$ values, into dust explosion classes (see Table 2).

TABLE 2
DUST EXPLOSION CLASSES

Dust explosion class	$K_{\max}$ bar.m/s
St ₁	≤200
St ₂	>200 ≤300
St ₃	>300

3.4.4 Minimum ignition energy (MIE)

For an assessment of the hazard in processing plants, knowledge of the minimum ignition energy of a dust cloud is necessary where combustible dust may be present. This value can conceivably establish the extent and hence cost of protective measures. Finding the minimum ignition energy involves testing for the failure to ignite. The MIE of a combustible substance is the lowest value of the electrical energy stored in a capacitor, which upon discharge, just suffices to ignite the most readily ignitable fuel/air mixture at atmospheric pressure and room temperature. Various test apparatus are used worldwide to determine the MIE. To assure a standardized test procedure, a third generation test apparatus known as MIKE 3 (Figure 3) was developed by Kuhner AG, Switzerland.

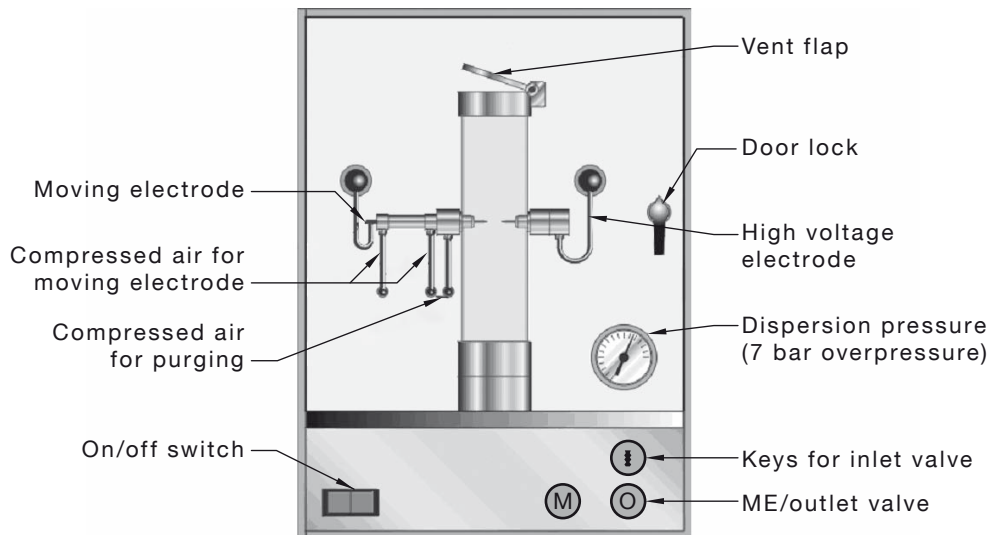


FIGURE 3 TEST OF MINIMUM IGNITION ENERGY (MIE)

The MIE is usually quoted as a range. The lower value represents the highest energy at which no ignition is found in at least 10 experiments. The higher value, on the other hand, is the lowest energy at which the dust/air mixture is just ignited. No ignition < MIE < ignition. The MIE is generally obtained with an inductance in the discharge circuit. However, to assess the incendivity of electrostatic discharges in dust/air mixtures, the MIE should be determined without an inductance in the discharge circuit.

Tests should be conducted with dust clouds of optimum dust concentration for ignition and having the lowest turbulence level experimentally obtainable.

Determining the MIE is described in AS/NZS 61241.2.3.

3.4.5 Minimum ignition temperature (MIT)

This MIT is the minimum temperature at which a dust cloud will auto-ignite. The cloud is exposed to air and heated to various temperatures in a furnace. Ignition is indicated by visual observation of a flame. The chemical nature of the dust, as well as its concentration, particle size, moisture content, and surface area all affect the result.

Determining the MIT is described in AS/NZS 61241.2.1, based on the Godbert–Greenwald furnace.

3.4.6 Test requirements

Where no safety data are available, the required tests should be done before introducing a product into a process. The test laboratory should repeat the requisite tests whenever local management suspects that an operation has become more hazardous. This may increase as a result of—

- (a) modifications in the production process (including preparatory steps) or equipment substitutions;
- (b) irregularities during production; or
- (c) changes in the manufacture or quality of any raw or auxiliary materials.

Due to changes in governmental laws, international regulations, and testing technologies, the relevance of specific tests should be checked at least once every five years.

3.5 SAMPLING OF DUSTS FOR TESTING

As part of a general philosophy there is a need for testing of representative dust samples. Chemical composition, moisture content, and particle size and shape distributions, affect both the ignition sensitivity and explosibility. Therefore, the dust sample tested should be representative of the dust or powder in the industrial process of concern. It is useful to distinguish between two different levels of sampling. The first, and often most crucial, is the initial collection of dust in the industrial plant. Chemical composition, moisture content and particle size in samples taken from the main product stream, a dust filter, and a shelf or beam in the workroom, may vary substantially. It is important, therefore that the initial sample be collected at a location and under operational conditions that ensures that it is really representative of the dust that creates the dust explosion hazard to be assessed.

Allen, Appendix B [Ref. 6] described methods for collecting dust/powder samples from bulk material in terms of—

- (a) sampling from a moving stream of powder;
- (b) sampling from a conveyor belt or chute;
- (c) sampling from a bucket elevator;
- (d) bag sampling;
- (e) sampling spears;
- (f) sampling from wagons and containers; and
- (g) sampling from heaps.

If the dust is to be collected from a gas stream, special precautions are required for ensuring representative sampling. As discussed in [Ref. 6], these relate both to the design of the sampling equipment and to the way in which the equipment is used. Whenever the sample is obtained by suction from a gas stream, it is important to ensure the sampling conditions are iso-kinetic. Otherwise a sample of non-representative particle size distribution can result.

Once the main dust/powder sample has been collected, it remains to divide it into smaller sub-samples, down to the level required for a single dust ignitability or explosibility test. For some tests this can mean quantities as small as 0.1 g. If the initial main sample is a bag of 50 kg, in which significant segregation of particle sizes may exist, picking samples of 0.1 g directly from the bag may not ensure the required degree of representativeness of the samples. In order to solve the problem of producing representative sub-samples, various apparatuses and methods have been developed. Allen [Ref. 6] distinguished between—

- (i) scoop sampling;
- (ii) coning and quartering;
- (iii) table sampling;
- (iv) chute sampling;
- (v) the spinning riffler; and
- (vi) other devices.

In general, the spinning riffler has proven to yield the most homogeneous sub-samples, and this method is recommended in most cases.

If a representative sample cannot be obtained the best compromise is a prepared sample with a median particle size $\leq 63 \mu\text{m}$ and a maximum size fraction of $250 \mu\text{m}$.

For further information see Appendix B [Ref. 6, pp 485-553] and VDI 2263.

3.6 HAZARDOUS PROCESSES

3.6.1 Introduction

The following processes are examples that have been found to be hazardous across a wide range of industries.

3.6.2 Filling and emptying operations

Filling and emptying operations can lead to the formation of dust clouds, and the possibility of generating static electricity which may ignite product inside the equipment or container. Particular care should be taken to ensure that ventilation and duct collection systems do not transfer the risk to another part of the plant. The design should minimize the exposure of operators to dust clouds during filling and emptying operations. Spillage, damage to transport containers and hazards from hot/cryogenic materials should be considered.

3.6.3 Loading bulk materials into flammable solvents

The possible generation of static electricity may be particularly important when loading powders into flammable liquids due to the flammable vapours present on the surface of the liquid.

If possible, load solids into batch reactors before flammable liquids. Allowing powders to fall through non-conductive materials will generate static electricity. Other methods of addition such as pre-blending or infusion into a recirculating line can also be considered.

3.6.4 Flexible intermediate bulk containers (FIBC)

Hazards associated with the use of flexible intermediate bulk containers (FIBCs) include thermal decomposition, possibly exacerbated by compaction and the generation of static electricity which can discharge and may ignite any flammable atmosphere in the vicinity. Delayed discharge may occur some considerable time after filling. As with all containers, static discharge may occur within the FIBC during filling. Because there are several protection methods used to prevent hazards arising from the generation of static electricity during filling and emptying FIBCs, the precautions appropriate to the specific type of FIBC should be taken. For example, Type D conductive bags are earthed (grounded).

3.6.5 Mixing

Dry mixers generate dust clouds. They often have moving parts and bearings which can generate heat. Unsecured lids can become missiles in the event of an explosion. The potentially large quantity of product within mixers can contribute to secondary explosions if the mixer bursts or falls over.

3.6.6 Dust separation

Dust collection devices present possible explosion hazards due to explosive dust concentrations. The high velocities in cyclones mean that foreign matter can generate impact sparks. Bag filters may contain large amounts of product, and may have moving parts which may provide ignition sources. If the bag filter medium is constructed of synthetic fabrics it could accumulate high static electric charges. Explosions can propagate through a plant via the dust collection system.

3.6.7 Spray and fluidized bed dryers

The major explosion hazards associated with spray and fluidized bed driers are self-ignition of deposits of solids or liquids on hot surfaces, or the prolonged exposure of thick layers of powder to high ambient temperatures. Friction, impact sparks and static electricity are also potential ignition sources.

3.6.8 Milling

Many mills may be susceptible to damage from foreign objects which can cause sparks and overheating. If the discharge from a continuous mill is blocked, the mill may overheat. Failure of inerting systems on mills represents a risk of explosion. Batch mills present the same hazards as mixers.

3.6.9 Sifters and sieves

Sifters and sieves contain explosive concentrations of dust. Frictional heating from foreign matter trapped within the devices is a hazard. Static electricity is another hazard.

3.6.10 Pneumatic conveyors

Impact sparks from foreign matter and static electricity are the main ignition sources in pneumatic conveyors. Explosions propagating along such conveyors can accelerate and so create very high explosion pressures.

One or more pressure relief devices (valve or bursting disc type) for both positive and negative pressure pneumatic systems should be located, sized and set to relieve at pressures designed to protect the system components, including explosion vents, from pressures created by the blower.

NOTE: Where a system or any part of a system operates at a positive or negative pressure, the system may need to be designed in accordance with boiler and pressure vessel codes.

3.6.11 Belt conveyors

The design and installation of belt conveyors should take into account the possible creation of dust clouds at the filling and emptying points. Pulleys and idlers and their bearings can provide ignition sources if they overheat due to lubrication failure or dust build-up. The use of fire retardant antistatic conveyor belting material should also be considered. Belt slippage or mistracking can cause local heating and lead to a dust explosion.

3.6.12 Vibratory conveyors

The design and installation of vibratory conveyors should take into account the possible creation of dust clouds at the filling and emptying points. They should be restrained to prevent their becoming missiles in the event of a dust explosion.

3.6.13 Bucket elevators

The design and installation of bucket elevators should take into account the possible creation of dust clouds within the elevator casing. Pulleys and their bearings can provide ignition sources if they overheat due to lubrication failure or dust build-up. The use of fire retardant antistatic conveyor belting material should also be considered. Belt slippage or mistracking can cause local heating and lead to a dust explosion. Plastic buckets can build up static and cause ignition. Frictional heating by the movement of buckets across build-up at the bottom of the casing can also cause ignition.

Where the elevator cannot withstand explosion pressure, venting should be considered at the top and bottom of bucket elevators, and at intermediate points when the elevator height exceeds 5 m.

3.6.14 Screw feeders

The design and installation of screw feeders should take into account the possible creation of dust clouds at the filling and emptying points. Bearings can provide ignition sources if they overheat. Misalignment of screws can cause frictional sparks.

3.6.15 Transport of containers

Where there is a likelihood that the handling of the material can cause an electrostatic charge capable of igniting the product, then the following precautions should be taken:

- (a) Transfer of powders should be in antistatic containers.
- (b) All wheeled containers, hand trucks and lift trucks should have non-sparking static conductive tyres and wheels.
- (c) All containers should be effectively bonded/earthed during filling and emptying.

3.6.16 Vehicles

Vehicles may act as an ignition source due to—

- (a) impact;
- (b) electrical equipment;
- (c) hot surfaces (exhaust, brakes);
- (d) static charges; or
- (e) hot exhaust particles.

Appropriate consideration should be given to the suitability of all vehicles used in a hazardous area.

3.6.17 Storage in vessels, silos and bunkers

Storage of some materials, particularly if hot, in bulk can lead to self-heating if stored for some time. Deflagration vents should be located above the maximum filling level of the material contained.

3.6.18 Exhaust equipment

Fans and other equipment for moving air should be located so the fan is on the clean side of any cleaning device. They should be equipped with ball or roller bearings located outside the fan casing and equipped with temperature indicating devices that give an alarm on over-temperature. Fan blades should be constructed of conductive non-sparking metal. Exhausts should discharge external to buildings. Ducted exhaust systems can propagate explosions through a plant.

3.6.19 Vacuum cleaners

Vacuum cleaners present several potential hazards. Sparks from electric motors, generation of static electricity in flexible hoses, the impact of foreign material and the impact of the nozzle are possible ignition sources. Ducted vacuum cleaning systems can propagate explosions through a plant. Risk of explosion hazard can be minimized by selection of appropriately rated electrical equipment, antistatic/conductive construction materials and earthing. Pneumatically powered venturi vacuum cleaners should be considered for applications where electric motive power presents a hazard. Training in safe housekeeping practices should be provided to all staff involved in operating, cleaning and maintaining equipment in areas subject to dust release.

3.7 RISK ASSESSMENT

3.7.1 Consequence assessment

3.7.1.1 General

The risk of a dust incident can be considered as the product of the likelihood of the incident and the severity of undesired consequences. Details of calculations used to determine the magnitude of these consequences may be found in other documents including VDI 3673.1 and NFPA 68.

The relevant parameters to be considered are outlined below.

3.7.1.2 *Size of fire*

3.7.1.2.1 *Fire spread through equipment*

Ignition of a combustible mixture in a vessel to which a pipe, duct or adjacent vessel is attached results in a flame front that generates considerable turbulence ahead of itself and pre-compresses the combustible mixture in the pipe or duct. When the flame front reaches the entrance to the pipe or duct, it is fully developed and turbulent. The result is a flame front that propagates into the pipe or duct with much greater initial violence than that which would result from spark ignition in the pipe or duct itself.

3.7.1.2.2 *Release from vents*

Normally when dust deflagrations occur, there is far more dust present than there is oxidant to burn it completely. When venting takes place, large amounts of unburnt dust are vented from the enclosure. Burning continues as the dust mixes with additional air from the surrounding atmosphere. Hence a very large and long fireball of burning dust develops, which can extend downward as well as upward. The size of the fire ball depends on many factors including the dust characteristics, the vent opening pressure, the size of the vessel, the shape of the vessel, etc. Personnel enveloped by such a fire ball are unlikely to survive. The potentially large size of the fireball extending from the dust deflagration vent should be considered when locating vents and vent ducts so as to avoid hazards to adjacent equipment and personnel. If the fireball cannot be accommodated within the application environment, alternative protection means should be implemented.

The preferred practice is to vent explosions outside buildings wherever practicable. Where venting inside buildings is unavoidable, measures should be taken to mitigate any consequences and such measures include—

- (a) flameless pressure venting devices (quench device with dust barrier);
- (b) the building itself has adequate volume and is vented to relieve overpressure; and
- (c) blast deflectors to direct the explosion products away from areas to which personnel are allowed access during plant operations.

3.7.1.2.3 *Release from combustible fittings*

If an explosion or fire occurs within equipment fitted with combustible fittings such as rubber or plastic flexible joints, the combustible material may fail due to the heat or due to the overpressure caused by the combustion of dust within the equipment. Flames, unburnt powder and/or overpressure may then be released through the failed fittings in the same manner as a vent.

3.7.1.2.4 *Impingement on adjacent equipment*

If flames are released from the equipment in which the deflagration occurs, these may impinge on and ignite adjacent combustible materials (e.g. packaging or stockpiles of processed material) as well as disable safety or other equipment required for use.

3.7.1.2.5 *Thermal effects*

There is a thermal hazard associated with fires and explosions. This thermal hazard exists both within the enclosure and in the path of a vented flame.

3.7.1.2.6 *Secondary explosions*

A secondary explosion will result in a fireball outside the equipment in which the primary explosion was initiated. The fireball will often engulf the work area as dust is dislodged and suspended prior to ignition by the primary explosion. Personnel caught within a secondary explosion have little chance of survival due to flame inhalation. The size of a secondary explosion is limited by the quantity of dust.