Workplace Safety and Health Guidelines

Combustible Dust

WSHCOUNCIL

Tripartite Alliance for Workplace Safety and Health

Year of issue: 2025

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1. Introduction

Solid combustible materials can burn rapidly when in a finely divided form such as dust. When such combustible dust is suspended in air at an optimal concentration under specific conditions, it can pose an explosion hazard. The force from such explosions can cause fatalities, injuries, and structural damage.

1.1 Objectives

This set of Guidelines serves to introduce combustible dust hazards and provides guidance on identifying, evaluating, and controlling the risk of fires and explosions due to combustible dust. The Guidelines also cover information on the Workplace Safety and Health (WSH) regulatory requirements for combustible dust and complements the Approved Code of Practice" Singapore Standard 667 : 2020 – Code of practice for handling, storage and processing of combustible dust" (SS 667 : 2020).

1.2 Scope

This set of Guidelines applies to all workplaces specified in the WSH Act that handle, sort, pack, store, process, manufacture or use combustible dust.

2. Understanding Combustible Dust

Ignition of combustible dust clouds can lead to fires and explosions. The first step in implementing preventive and mitigating measures to ensure a safer working environment, is to raise awareness and understand the risks associated with combustible dust.

2.1 Definition of Combustible Dust

Combustible dust refers to any finely divided combustible particulate solid (regardless of size, shape, or chemical composition) when processed, stored, or handled in the facility, that presents a flash fire hazard or an explosion hazard when suspended in air or the process-specific oxidising medium over a range of concentrations.

2.2 Types of Combustible Dust

Combustible dusts can be broadly grouped into four types: metals, chemicals, plastics, and organic matter.

Metallic dusts (e.g., aluminium, magnesium) may be generated during industrial processes like grinding or welding. Chemical dusts (e.g., sulphur, calcium acetate) may be formed during industrial manufacturing. Plastic dusts (e.g., polyethylene, polypropylene) may be produced during polymer handling. Organic matter dusts (e.g., sugar, tea) may become airborne during food packaging operations.

More examples of combustible dust can be found in Annex A.

2.3 Inherent Properties of Combustible Dust

Explosibility characteristics of combustible dust can be typically measured by three key parameters, but not limited to:

K_{st}[1] is a deflagration index or dust-specific explosivity measure of a dust cloud. The larger the value of K_{st}, the more severe the explosion.

Minimum Ignition Energy (MIE) is the lowest capacitive spark energy capable of igniting the most ignition-sensitive concentration of a combustible dust-air mixture as determined by a standard test procedure.

Minimum Explosible Concentration (MEC) is the minimum concentration of a combustible dust suspended in air that will support an explosion, measured in mass per unit volume.

[1] "st" is for staub, the German word for dust.

2.4 Flash Fire and Explosion

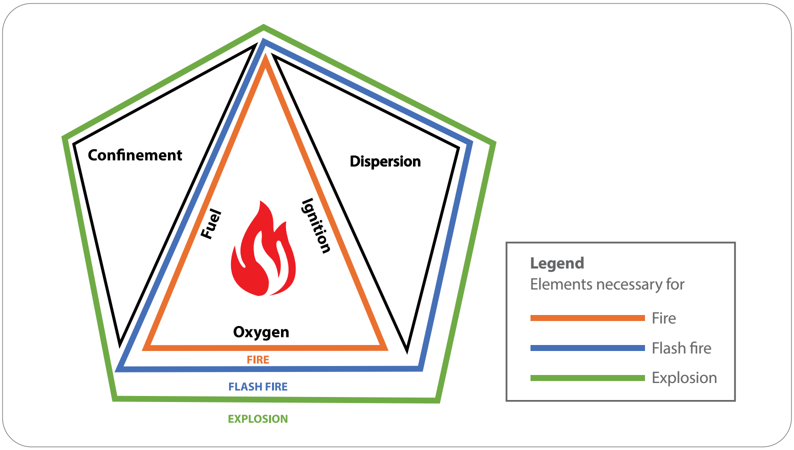
Combustible dusts present two distinct hazards: (i) flash fires and (ii) explosions.

i A flash fire is characterised by a momentary flame that moves rapidly through a combustible dust cloud. It rarely lasts for more than a few seconds but can cause severe injury to any worker(s) in its path.

ii Under specific conditions such as confinement and dust cloud formation, an explosion can result from the rapid combustion of dust particles, leading to devastating consequences, including structural damage, severe injuries, and multiple losses of lives.

To prevent a combustible dust-related accident, one should first understand the elements that can result in a flash fire or explosion. The elements necessary for a dust-related flash fire or explosion to occur are summarised in Figure 1.

Figure 1: **Dust explosion pentagon** ***(Figure 1 is adapted from SS667 : 2020 with permission from Enterprise Singapore.)***



The Fire Triangle (the orange triangle in Figure 1) comprises FUEL, OXYGEN (present in air), and an IGNITION source. A flash fire can occur when the additional element of DISPERSION (the blue quadrilateral in Figure 1) is present. Dispersion occurs when combustible dust is suspended in air.

A combustible dust explosion can occur when both the DISPERSION and CONFINEMENT elements are present (the green pentagon in Figure 1; commonly referred to as the dust explosion pentagon).

Table 1: **Elements for a combustible dust explosion**

Element	Description
FUEL – Combustible dust	Combustible dust particle size typically determines the ease of ignition and the consequences of a combustible dust explosion. Some other factors affecting the explosiveness of dusts include chemical composition, moisture content, ambient humidity, oxygen availability, particle shape, and dust concentration in the air. Dust from the same material, varying in size, shape, and moisture content, can have different ignitability and explosibility characteristics. The physical properties of dust may change during manufacturing, use or processing. Any combustible dust with a K_{st} value greater than zero can potentially cause dust explosion. A list of combustible dust examples can be found in Annex A.
IGNITION	An ignition source in these Guidelines refers to a source of energy sufficient to initiate combustion of dust particles. These include, but not limited to naked flames, sparks, static electricity, and hot surfaces of engines. A list of possible ignition source can be found in Annex B.
OXYGEN	Oxygen in the air supports combustion. Combustion occurs when the fuel (dust particles) reacts with oxygen. Without sufficient oxygen, a fire or explosion cannot sustain itself.
DISPERSION	Dust explosion may occur when dust particles are suspended in the air and reach the minimum explosible concentration. This dispersion creates a cloud of dust that can ignite if it meets an ignition source. Lower concentrations might not support an explosion, while too high of a concentration can inhibit combustion because there is not enough oxygen relative to the fuel.
CONFINEMENT	When a combustible dust cloud ignites in an enclosed or semi-enclosed space, the pressure from the primary explosion can build up. This often lead to secondary explosions and severe damage. Confinement increases the destructive power of a dust explosion by not allowing the pressure and flames to dissipate.

To prevent a flash fire from occurring, measures should be put in place to prevent the four elements in the blue quadrilateral from co-existing.

To prevent a combustible dust explosion from occurring, put in place measures to prevent the five elements in the green pentagon from co-existing.

To arrest a flash fire or explosion, the removal of one or more of the necessary elements for its existence is required.

The above concepts are essential for addressing the hazards associated with combustible dusts.

2.5 Combustible Dust Explosion Scenarios

There are three key scenarios where a combustible dust explosion can occur:

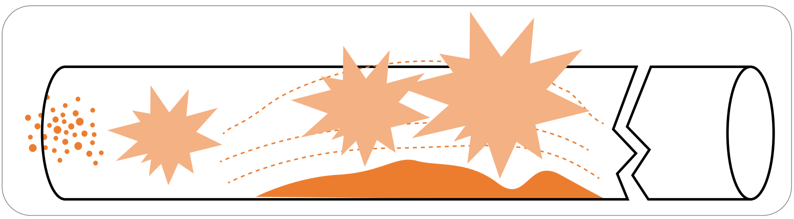
2.5.1 Dust Explosion Within a Process System

A combustible dust explosion can occur in confined spaces within process systems, such as ventilation ducts, dust conveyor belts systems, storage silos and dust collection systems. When the concentration of airborne combustible dust rises above the MEC and meets an ignition source, a flash fire or explosion could occur.

The situation could be escalated if more dust becomes suspended due to the initial explosion, providing additional fuel to the fire and cause a secondary explosion.

A dust explosion may cause the process equipment to rupture. Even if the equipment were to remain structurally intact, it can serve as a conduit for the explosive pressure to travel longer distances, causing downstream damage to the process line.

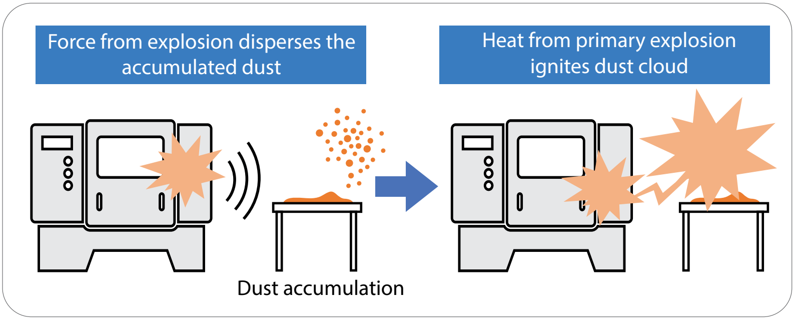
Figure 2: **An initial dust explosion can trigger secondary explosions inside a process line due to additional dust dispersion**



2.5.2 Secondary Dust Explosion

Accumulations of combustible dust on surfaces around machines can pose an explosion hazard. The force of a primary explosion originating from an equipment or machine can disperse accumulated dust into the air. With the heat from the primary explosion as an ignition source, the suspended dust can trigger a secondary explosion.

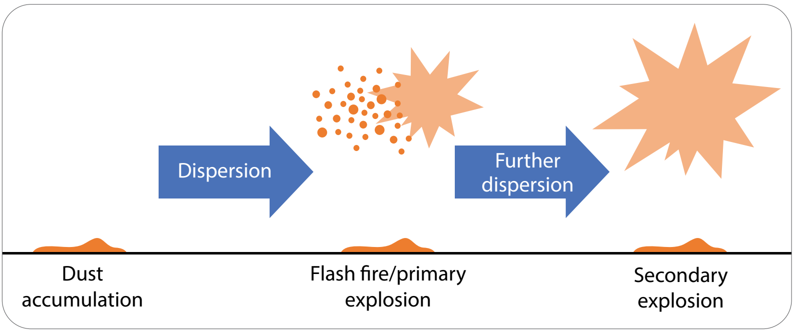
Figure 3: An external primary explosion can trigger secondary explosions



2.5.3 Explosion Triggered by Suspended Dust

A dust dispersion event (e.g., sweeping up combustible dust accumulated on the floor) can result in a primary dust explosion in the presence of an ignition source (e.g., electrostatic ignition, a hot surface). The primary explosion can further suspend dust accumulated on surfaces, and the newly suspended dust could trigger one or more secondary explosions.

Figure 4: Accumulated dust can lead to dust explosions



In all the above scenarios, secondary explosions may be more devastating than the primary explosion due to the increased quantity and/ or concentration of dispersed dust.

3. Relevant WSH Legislation

Compliance with WSH legislation on combustible dust is crucial in preventing combustible dust-related accidents safeguarding workers.

3.1 WSH Act

The WSH Act requires stakeholders to take reasonably practicable measures to ensure the safety and health of persons in the workplace. The Act places responsibility on stakeholders, including employers, occupiers, manufacturers, and suppliers who have it within their control to ensure safety at the workplace. It focuses on WSH systems and outcomes, rather than merely on compliance.

Note

From 1 January 2025, the list of hazardous substances in the Fifth Schedule of the WSH Act is expanded to include combustible dust. The duties of manufacturers and suppliers have been extended to include combustible dust (see WSH Act Part 4 for details). A list of combustible dust can be found in the Fourth Schedule of the WSH (General Provisions) Regulations.

3.2 WSH (Risk Management) Regulations

Risk management is the process of identifying, evaluating and controlling risks at the workplace. It includes communicating the risks to employees, contractors, and other relevant stakeholders. The WSH (Risk Management) Regulations state that employers, self-employed persons and principals (including contractors and sub-contractors) are responsible for identifying safety and health hazards at workplaces and taking measures to eliminate or reduce the risks.

3.3 WSH (General Provisions) Regulations

The WSH (General Provisions) Regulations include the safe management of combustible dust kept, stored, used, handled or generated in the workplace and precautions to be taken to prevent fires or explosions. The Regulations also state the requirements on hazard communication of combustible dust through labels and Safety Data Sheets. Depending on the type and amount of dust at the workplace, factories may be required to notify the Ministry of Manpower (MOM) and the owner of the factory.

4. Risk Assessment

The occupier of the workplace is responsible for determining whether the materials used are combustible dusts. As a part of risk assessment, combustible dust-related hazards from work activities need to be identified and evaluated for their associated risks and addressed using relevant risk controls. These steps and their results should be documented, and one of the ways is in the form of a dust hazard analysis (DHA) report.

4.1 Dust Hazard Analysis (DHA)

A DHA is a systematic way to identify and evaluate the potential for fire, flash fire or explosion due to the presence of particulate solids in a process or facility, and documents the controls required to manage the risk. The DHA should be performed or led by a competent person[2].

The overall method for conducting a DHA is summarised in the flowchart provided in Figure 5. Detailed information on the DHA flowchart is given in SS 667 : 2020.

The DHA includes identification of the storage areas, process areas and handling facilities where fire, flash fire and explosion hazards exist. Where a combustible dust hazard exists, evaluation includes:

a. Safe operating ranges for process equipment;
b. Likelihood and potential consequences of fire, flash fire and/or explosion;
c. Normal (expected) dust accumulation rate and non-routine dust accumulation rate; and
d. Safeguards in place to manage fire and explosion events and recommendations on the additional safeguards.

As far as practicable, fugitive dust[3] should be prevented from settling on surfaces. If there is a possibility of dust accumulation, the DHA should define the maximum allowable layer thickness or area density of the deposit, the maximum allowable surface area covered, and minimum personal protective equipment (PPE) workers are to put on.

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[2] A competent person means a person who has sufficient experience and training to perform the work required to be carried out. One example of such training is the Combustible Dust Hazard Competent Person Course conducted by The Institution of Engineers, Singapore.

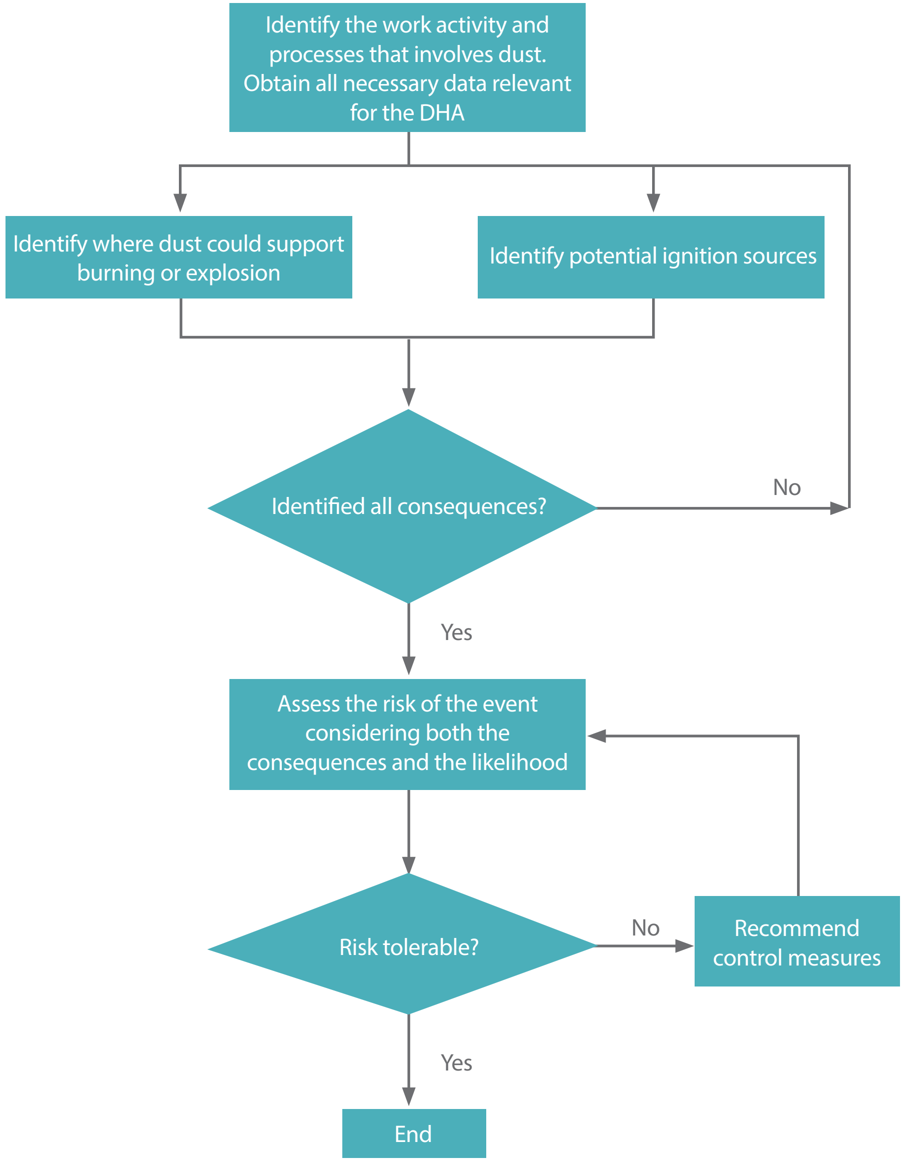
[3] Fugitive dust refers to airborne particles or particulate matter generated from work activities and is emitted or escapes into the atmosphere of the work environment.

DHA findings should be documented and retained along with other risk assessment forms. Similar to risk assessments, a DHA is recommended to be reviewed at least once every three years or upon the occurrence of any bodily injury to any person as a result of exposure to a hazard in the workplace. It should also be reviewed whenever there are significant changes to work practices or procedures, which may include changes in the process materials, operations and facilities associated with the process.

Note

DHA method used should be appropriate to the nature and scale of the hazard and scale of operation. Examples of methods for DHA can be found in SS 667 : 2020.

Figure 5: DHA flowchart *(Figure 5 is adapted from SS 667 : 2020 with permission from Enterprise Singapore.)*



Risk assessment for combustible dust involves identifying, evaluating, and controlling hazards due to the presence of combustible dust in the workplace.

4.2 Identifying Combustible Dusts

It is important to identify if a dust is combustible. Early identification facilitates proactive measures to be put in place to ensure workers' safety and prevent accidents.

Some ways to identify combustible dusts are through:

4.2.1 Warning Labels

Warning labels on container or package will include information on the hazards involved in the hazardous substance stored in the container or package. If the substance is a combustible dust, the warning statement "Warning: May form explosible dust-air mixture if dispersed" will be explicitly stated on the label.

4.2.2 Safety Data Sheet (SDS)

An SDS provides comprehensive information about a substance or mixture. It includes the properties of the substance, the hazard(s) it presents, and the safety precautions to be taken when handling it. A combustible dust hazard is present if the warning statement "Warning: May form explosible dust-air" mixture if dispersed" is stated in Section 2 of the SDS.

Manufacturers and suppliers are required to update their SDSs when substance information changes, new safety and health data emerges, there is new emergency information, or when new regulations come into force, among other scenarios.

4.2.3 International References

Additional lists of combustible dust are available at:

- NFPA 660 Standard for Combustible Dusts and Particulate Solids.
- GESTIS-DUST-EX Database on Combustible Dust, developed by the Institute for Occupational Safety and Health of the German Social Accident Insurance.

> It is important to recognise that the material used at workplaces may vary in particle size, moisture content, environmental conditions, etc. Therefore, due diligence should be exercised when referencing these information sources to ensure their applicability and accuracy in the specific context.

4.2.4 Laboratory Tests

If the combustibility of a dust is unknown, the dust can be classified based on one of the following:

a. UN Recommendations on the Transport of Dangerous Goods, Manual of Test and Criteria Part III, Sub-section 33.2.1.

b. VDI 2263 Part 1, Burning Behaviour.

If the explosivity of a dust is unknown, the dust can be tested based on one of the following:

a. "Go/No-Go" screening test methodology described in ASTM E1226, Standard test method for explosibility of dust clouds.

b. ASTM E1515, Standard test method for minimum explosible concentration of combustible dust.

c. ISO/IEC 80079-20-2:2016 Explosive atmospheres – Part 20-2: Material characteristics – Combustible dust test methods.

4.3 Combustible Dust Control

Hazard control and risk reduction can be achieved through the Hierarchy of Control (see Figure 6). Upstream risk controls, such as elimination, substitution and engineering controls are more effective in reducing or controlling risk and should first be considered.

For improved risk control, various controls in the Hierarchy of Control may be applied in combination. For example, engineering controls like local exhaust ventilation to remove combustible dusts from work areas can be implemented concurrently with administrative controls, such as establishing safe work procedures and promoting awareness amongst workers.

Figure 6: Hierarchy of Control

Elimination	E.g., removing the use of combustible dust in processes.
Substitution	E.g., replace material in powder form to paste/ slurry form.
Engineering Controls	E.g., use of local exhaust ventilation to prevent accumulation of combustible dust.
Admin Controls	E.g., regular cleaning of the workplace to prevent dust accumulation.
PPE	E.g., fire retardant clothing, static dissipative safety shoes and dust respirator.

4.3.1 Elimination

Hazard elimination is the most effective method of risk control. Elimination focuses on removing the hazard at source. Elimination is usually applied at the earliest stages of process or facility planning and design, and especially before introducing a new process or new materials.

Another example of elimination would be to do away with the introduction or use of a combustible dust.

While elimination is effective, it is not always possible or practical to achieve. For example, a bakery cannot produce bread without flour, and a factory manufacturing wooden furniture cannot do so without generating sawdust. In these scenarios, the hazard cannot be eliminated without fundamentally changing the nature of the business.

Should elimination be unattainable, the other methods or a combination of methods in the hierarchy of control, such as substitution and engineering controls, should be considered to manage WSH risks.

4.3.2 Substitution

Substitution involves replacing a process or material with a less hazardous alternative. For example, using a material of higher MIE significantly reduces the likelihood of ignition. Another example is to substitute materials used or generated in work processes from a powdered form to pellets, a paste or a slurry.

4.3.3 Engineering Controls

Engineering controls are physical means that reduce the likelihood and/or reduce the consequences of a dust explosion. Engineering controls can prevent a combustible dust explosion or, as a last resort, contain or offer protection against an explosion should one occur. Without appropriate engineering controls, the processing or handling of combustible dust within enclosed equipment, such as in a process plant or a dust collection system, can result in an explosive atmosphere.

Instruments and equipment that are installed in a facility should be adequately designed to prevent introduction of ignition sources to the work area. For example, a Hazardous Area Classification (HAC) can be conducted to better understand physical locations where dust hazards may arise. In areas where clouds of combustible dust are present in air - whether continuously, for long periods, or frequently for short periods - more stringent ignitions controls should be implemented. This classification can serve as a basis for selecting and installing equipment suitable for use in classified hazardous areas. HAC procedures can be established in accordance with standards such as IEC 60079-10-1:2020 Classification of areas - Explosive gas atmospheres.

Explosion prevention

Explosion prevention involves putting in place proactive measures to avoid an explosion by removing or reducing one or more elements in the dust explosion pentagon. An example is the creating inert atmospheres within powder handling units to eliminate the possibility of an ignition. At low or no oxygen levels, combustion of combustible dusts are almost impossible, hence, nitrogen can be used instead to reduce the presence of oxygen within processing equipment. Oxygen analysers can be employed to ensure the effectiveness of the inert gas blanketing. It is important to note that the use of inert gases poses asphyxiation risks, which needs to be managed carefully.

Below are examples of dust explosion prevention:

Ignition control: Control ignition sources, such as flames and electrostatic sparks, to prevent dust explosions. Use only suitable flame-proof equipment or non-sparking tools in areas with combustible dust. Effective bonding and grounding of equipment can also prevent the accumulation of electrostatic charges. Carry out annual testing to ensure the effectiveness of bonding and grounding solutions.

Dust capture: Equipment and processes generating combustible dust should be equipped with a dust collection system suitable for handling combustible dusts. A dust collector system works by capturing dust at the point of generation and then separating the dust from the air, before discharging cleaned air back into the environment.

Basic components of a dust collection system include a dust extraction system (e.g., via local exhaust ventilation), air cleaning system, associated ducting network, and a fan blower. Common types of dust collection equipment are inertial separators (e.g., cyclone separators), anti-static air filters, wet scrubbers, and electrostatic precipitators.

A dust collection system and its explosion protection features should be maintained at regular intervals according to the manufacturer's recommendation. For example, air filtration media should be checked and replaced regularly to maintain its filtration efficiency.

Location of dust collectors

The dust extraction system should be designed with its dust capture inlet as close as possible to the source of dust. Ideally, the air cleaning system should be located outdoors to minimise the potential damage from an explosion affecting the facility and injuring its occupants. Where this is not possible, for example, due to space constraints or the operational requirements of the facility, additional control measures for indoor dust collectors should be considered, such as the inclusion of spark detectors and fire extinguishing system.

A liquid dust suppression system may also be used to "rain out" suspended dusts. This wet system involves spraying a fine mist or fog to achieve this purpose, with water being the liquid commonly used. In a liquid dust suppression system, nozzles are strategically positioned near the source of dust emissions to effectively suppress the dust before it becomes airborne.

Explosion protection

While measures are in place to prevent a dust explosion, additional measures should be put in place to limit the consequences of an explosion.

Below are examples of dust explosion protection:

Explosion suppression system: An explosion suppression system typically consists of a pressure or heat detector, a control unit, and a combustion suppressant. Once a pressure build-up or hotspots are detected, the system will automatically inject the combustion suppressant into the process to reduce the potential for explosion. The nozzles in such systems are specially designed to quickly and effectively disperse the combustion suppressant inside the process, thereby maximising coverage for explosion suppression.

Figure 7: **Example of an explosion suppression system**

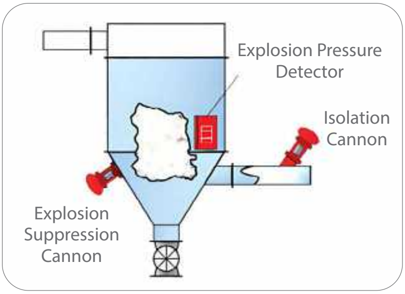


Figure 8: **Example of a dust collector with explosion suppression system**

Figure 9: Example of an indoor dust collector with explosion suppression system

Figures 7–9 courtesy of BS&B Safety Systems Asia Pacific Pte. Ltd.

Explosion isolation device: Where there is the possibility of an explosion spreading to other work areas though interconnecting pipework, isolation devices may be used to stop the spread. Flame arrestors and mechanical barriers such as remotely operated valves or a high-speed knife gate can be installed to prevent the explosion from spreading through a process line.

Pressure protection systems: Explosion vents (ideally flameless) and pressure relief systems reduce the pressure build-up by releasing it into a controlled and safe area, directed away from work areas. Pressure relief systems can lower the likelihood of an explosion.

Figure 10: Example of an explosion venting/chemical isolation system

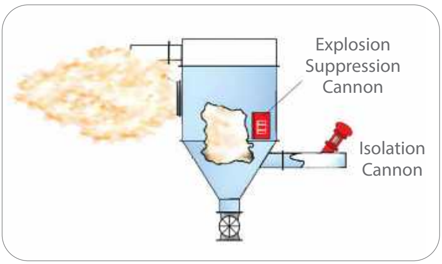


Photo credit: Figure 10 courtesy of BS&B Safety Systems Asia Pacific Pte. Ltd.

Figure 11: Example of flame free venting with mechanical isolation system

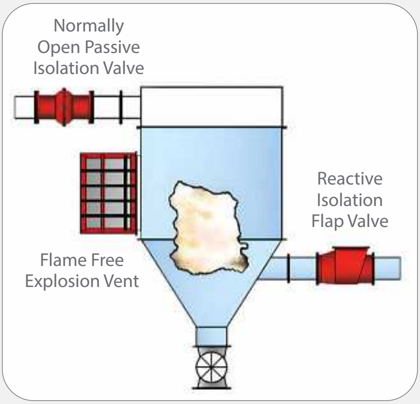


Photo credit: Image on the left courtesy of BS&B Safety Systems Asia Pacific Pte. Ltd.; image on the right courtesy of REMBE Asia Pacific Pte. Ltd.

For more information on the different engineering controls for explosion prevention and protection, refer to SS 667 : 2020.

4.3.4 Administrative Controls

Administrative controls eliminate or reduce exposure to a hazard by adherence to procedures or instructions. Examples include:

Safe work procedures: Safe work procedures should be established for tasks that use, store, manufacture, process, blend, convey, repackage, generate, or handle combustible dusts. For example, when transferring combustible dusts, carry out in smaller batches instead of pouring from bulk bags to minimise dispersion. Combustible dusts should be stored in closed containers or packaging in a well-ventilated area and kept away from ignition sources and process areas.

Equipment inspection and maintenance: Poorly maintained equipment may overheat or catch fire, providing an ignition source for combustible dust. Develop and implement a regular inspection and preventive maintenance programme which outlines the recommended frequency for equipment inspections and maintenance.

Management of Change: For replacement, modification or introduction of any new equipment in areas handling combustible dusts, adequate management of change should be implemented. This includes conducting risk assessments, ensuring adherence to relevant standards, documenting all changes, providing personnel training, and verifying correct implementation of modifications. These steps are necessary to maintain safety and compliance throughout the modification process.

Workplace housekeeping: Regular cleaning of the facility to remove dust from work areas, equipment surfaces, and floor can prevent dust accumulation. A facility cleaning schedule should be established, and workers should be trained on the safe housekeeping methods for combustible dust. Ensure suitable cleaning methods are adopted to minimise dust suspension during housekeeping activities. In particular, do not carry out dry sweeping or use compressed air if combustible dust is present. Instead, use wet cleaning methods or explosion-proof vacuum cleaning devices.

Figure 12: Example of an explosion-proof vacuum cleaner

Photo credit: Figure 12 courtesy of BS&B Safety Systems Asia Pacific Pte. Ltd.

Worker training and communication: Train employees on the hazards of combustible dust and the safe handling, storage, and housekeeping practices through toolbox talks and dedicated training sessions. An example of such training is the Combustible Dust Hazard Awareness Course. Workers should be reminded not to conduct hot work activity or smoke where combustible dusts are present.

Emergency Response Plan: Evacuation procedures and first responder actions should be established and implemented with drills regularly conducted. The emergency response plan should be reviewed and validated on a regular basis.

4.3.5 Personal Protective Equipment (PPE)

Workers working with combustible dusts should be equipped with the necessary PPE, e.g., flame retardant clothing, static dissipative safety shoes, dust respirators. For respiratory protection provided to workers, fit test should be conducted, and fit test records should be kept. Workers should also conduct fit checks (positive or negative pressure fit checks) on their respirators before using them. More information on respiratory protection programme can be found in SS 548 Code of practice for the selection, use and maintenance of respiratory protective devices.

Please refer to Annex C for a sample combustible dust hazard checklist.

5. Hazard Communication

Effective hazard communication for combustible dust can be achieved through labelling and informing building owners and landlords of the presence of combustible dust on the premises.

5.1 Hazard Warning Label

A label on the packaging of a combustible dust can increase hazard awareness, allowing for informed and proactive measures to be taken to prevent dust-related incidents. Labels can help quickly identify combustible dusts without the need to send an unknown dusts for laboratory testing.

The warning labels for any container of chemicals, plastics, and metallic materials that could pose a combustible dust hazard should conform with Singapore Standard 586 Part 2. The statement "Warning: May form explosible dust-air mixture if dispersed" should be indicated in the GHS label. A typical GHS label is shown in Annex D.

Manufacturers and suppliers should ensure that the label on the packaging is prominently placed and legible to avoid misinterpretation by users. The label should be clearly visible and not obscured by markings or attachments.

Workers should be informed about the presence of such labels and how to interpret them. They should also be encouraged to check the labels for signs of damage or tampering and be reminded to report or promptly replace damaged labels.

5.2 Communication to Workers

All workers at the workplace should be informed of the risks associated with handling combustible dust and the control measures available to manage those risks. Safe work procedures and risk assessments should be clearly communicated. This can take various forms, such as meetings, staff dialogues, trainings, notice boards and various electronic means, tailored to different groups within the company.

6. Case Studies

Case Study 1: Secondary Flash Fires Caused by Suspended Potato Starch Powder

Incident Description

On 24 February 2021, a large explosion occurred in a company involved in the business of manufacturing fire-retardant wraps or "fire clay". One of the main work processes involved the use of a heated mixer machine, which came with an external jacket for heat transfer fluid and built-in heaters. A key ingredient for the "fire clay" was potato starch.

Overheating of the heat transfer oil, combined with the use of the oil jacket as a closed system resulted in over-pressure within the mixer's oil jacket, causing it to rupture. The heat transfer oil in the jacket was released and aerosolised into fine droplets, which then ignited and triggered an explosion. The explosion overpressure suspended combustible potato starch powder in the area and resulted in subsequent flash fires when it was ignited.

The accident resulted in three deaths, five major injuries, two minor injuries, and severe property damage.

Figure 13: Accident scene showing damaged shutters of the worksite

Findings (specific to combustible dusts)

- Potato starch powder was allowed to accumulate on surfaces.
- Lack of emergency response plan to ensure effective and efficient evacuation.
- Not providing or ensuring the use of PPE such as fire-retardant clothing.

Lesson Learnt (specific to combustible dust)

- Capture combustible dusts at source. E.g., mechanical ventilation at the source of combustible dust generation.
- Control dust accumulation by establishing a housekeeping frequency to remove dust build-up in work areas, equipment, and ventilation systems.
- Put in place emergency action plans specifically addressing the potential for dust explosions, including evacuation procedures and first responder actions should be established and implemented.
- Provide and ensure workers working with combustible dusts are equipped with the flame-retardant PPE.

Please refer to the Report of the Inquiry Committee for the accident at Stars Engrg Pte Ltd on 24 February 2021 (Part 1 – Main report) for more information about this case.

Case Study 2: Combustible Dust Fire in a Food Manufacturing Company

Incident Description

A worker was cutting the support of an old conveyor pipe system with a cutting torch when flour poured out from the bottom opening of the silo. When the flour dust mixed with the surrounding air, a flash fire was triggered, and an explosion followed thereafter. The worker immediately switched off the cutting torch.

The injured worker suffered burns on his arms, face, and parts of the body, while the co-worker who came to his rescue suffered minor burns. The platform of the silo and electrical wiring were also damaged.

Findings

- The flash fire involving tapioca flour (a combustible dust) was triggered by the flame of the cutting torch (ignition source).
- A safe work procedure was not implemented for the cutting operation.

Lesson Learnt

- Equipment and processes generating combustible dust should be equipped with dust collectors and extraction systems to remove dust at its source and prevent it from becoming airborne.
- Ignition controls should be implemented to eliminate or reduce sources of ignition. E.g., A permit-to-work system should also be implemented for hot work activities such as welding and cutting.

Case Study 3: Flash Fire From Combustible Dust Leaves Worker With Burn Injuries

Incident Description

On 20 July 2022, a dust explosion occurred inside a grain dryer, causing a flash fire at the relief vent. A worker who was near the vent at the time of the explosion suffered burn injuries to his elbow.

Findings

- The dryer was intended to heat spent grains within its container to remove moisture. During handling and conveyance, the grains generated smaller grain particles. As the grains and their particles were heated, a combustible dust cloud formed within the confined space of the dryer.
- The investigation revealed that an ignition source was present within the dryer and inadequate explosion protection of the dryer led to uncontrolled venting, causing the worker's burn injuries.

Figure 14: Dryer machine used to dry spent grains.

Figure 15: **Inside the dryer, spade plates (left image) were installed to convey and elevate the spent grains for drying. However, the plate's securing mechanism was not adequately maintained. Loosened parts and foreign objects, including a lifting shackle (right image), were found in the dryer. These could generate sparks (as a possible ignition source) when impacting the inner walls of the dryer or other moving parts.**

Figure 16: **The force from the dust explosion spread to the relief vent which blasted open.**

Lesson Learnt

- Conduct a DHA to review the processes and equipment involving combustible dust which could pose fire or explosion risk at your workplace. The DHA should also identify suitable and adequate measures to control and mitigate dust explosion risks.
- Implement effective dust control measures where combustible dust is generated or dispersed during normal operation. Examples of dust control measures include:
  - Effective local exhaust ventilation system to remove any generated dust from the source as far as possible;
  - Suitable dust suppression system; and
  - Housekeeping procedures, which should include cleaning using explosion-proof vacuum cleaners or wet mopping. Dry sweeping should be avoided to reduce the formation of dust clouds.

- Ignition source control:
  - Prevent the accumulation of electrostatic charges through effective bonding and grounding of dust handling equipment (e.g., dryers, dust collectors, and transfer conduits). Carry out regular electrical continuity testing to ensure bonding and grounding effectiveness.
  - Use suitable explosion-protected equipment or flame-proof machinery (e.g., explosion-proof lighting, EX-rated forklift or motor) and non-sparking tools in areas handling combustible dusts.
  - Ensure foreign materials (e.g., tramp metal, loose components) that can generate sparks are excluded and removed from the processing system.
- Explosion prevention and protection:
  - Install sensors for early detection of heat or pressure build-up within the combustible dust storage facilities or dust handling equipment. The sensor may be interlocked with the dust handling equipment to automatically stop the equipment and/or release an explosion suppression agent.
  - Equip dust handling equipment with explosion relief vents to safely vent energy in the event of a dust explosion. Vent dimensions should be adequately sized to withstand the maximum force(s) expected should an explosion occur. Locate explosion relief vents away from work areas and walkways to protect persons at work.
  - Install isolation valves to protect connecting equipment and flame arrestors at dust handling units that could be activated in an emergency, to stop the flame from spreading.
  - Separate areas handling combustible dust from other work areas either with distance or isolation enclosure.
- Implement a regular inspection regime to ensure no loose parts in any dust handling equipment, and a preventive maintenance programme to ensure equipment is fit for continued service. Ensure dust collection systems and filters are also operating effectively and regularly maintained.
- Provide training, including refreshers, on combustible dust hazards and their controls. Clearly communicate the risks of combustible dust and safe handling practices. E.g., through toolbox briefings, warning signs, and safety data sheets.
- Provide workers handling combustible dust with the necessary PPE as specified in the safety data sheet, such as fire-retardant clothing and static dissipative safety shoes.

7. Reference

- Workplace Safety and Health Act
- WSH (Risk Management) Regulations
- WSH (General Provisions) Regulations
- MOM Circular on the hazards and controls of combustible dusts
- SS667: 2020 Code of Practice for handling, storage and processing of combustible dust
- SS508-2 Specification for graphical symbols - Safety colours and safety signs - Design principles for product safety labels
- SS586-2:2022 Specification for hazard communication for hazardous chemicals and dangerous goods – Part 2: Globally harmonised system of classification and labelling of chemicals – Singapore's adaptations
- SS586-3:2022 Specification for hazard communication for hazardous chemicals and dangerous goods – Part 3: Preparation of safety data sheets (SDSs)
- SS548:2022 Code of practice for the selection, use and maintenance of respiratory protective devices
- National Fire Protection Association (NFPA) 660 Standard for Combustible Dust and Particulate Solids
- Health and Safety Executive's publication on safe handling of combustible dusts
- International Electrotechnical Commission IEC 60079-10-1:2020 Classification of areas - Explosive gas atmospheres
- WSH Guidelines on Flammable Materials
- 6 Basic WSH Rules for Handling Combustible Dust

8. Acknowledgement

The WSH Council would like to thank Chung Shan Pte Ltd for the cover page photo, and BS&B Safety Systems Asia Pacific Pte. Ltd. and REMBE Asia Pacific Pte. Ltd. for the photos featured in these guidelines.

9. Annexes

Annex A — List of combustible dust

METALLIC		
Bronze Copper Iron Iron carbonyl	Manganese Silicon Tantalum Titanium	Zinc Aluminium Magnesium Niobium
CHEMICAL		
Adipic acid Ascorbic acid Calcium acetate Calcium stearate Carboxy- methyl-cellulose	Dextrin Lactose Lead stearate Methyl-cellulose Paraformaldehyde	Sodium ascorbate Sodium stearate Sulphur Anthraquinone
PLASTIC		
Epoxy resin Ethylene-vinyl acetate copolymer Melamine Polyacrylamide Polyacrylonitrile	Polyethylene Polypropylene Polyvinyl acetate Polyvinyl alcohol Polyvinyl butyral	Polyvinyl chloride Terpene-phenol resin Urea-formaldehyde-cellulose Phenolic resin Polymethyl acrylate
ORGANIC		
Alfalfa Apple Beetroot Carbon black Carrageenan Carrot Cereal (for example, barley, corn, oat, rice, rye and wheat) and their derivatives Charcoal Coal Cocoa Coconut and derivatives Coffee Coke Cotton and derivatives	Egg white Garlic Garlic (malted) Grains (spent) Grass Hops Lemon peel/ pulp Linseed Locust bean gum Malt Milk and derivatives Olive pellet Onion Parsley Peach Peanut	Peat Potato and derivatives Soot Soybean and derivatives Spice Sugar Sunflower seeds Tapioca Tea Tobacco Walnut Xanthan gum Yucca seeds Cellulose Cork Wood

Annex B — Examples of Ignition Sources

Ignition source is one of the five elements in the dust explosion pentagon. Potential ignition sources typically encountered are listed below:

Grouping	Potential ignition sources
Electrostatic charges	a) Spark b) Brush discharge c) Cone discharge
Mechanical equipment	a) Friction or impact created by machineries b) Overheated bearings c) Cutting, shaping, and planning equipment (e.g., woodworking)
Electrical installations	a) Electrical equipment b) Electrical wiring c) Stray electric currents
External sources	a) Hot work b) Hot surfaces c) Open flames d) Fuel-fired equipment e) Vehicles f) Lighted cigarette g) Lightning h) Stray electric currents i) Radiation j) Ultrasonic k) Shock waves l) Portable electronic equipment
Process sources	a) Self-heating b) Exothermic reactions c) Smouldering

Annex C — Sample Combustible Dust Hazard Checklist

	Yes	No	NA
Combustible Dust Hazard Identification			
Do you work with dust in your workplace?			
Is the dust combustible (i.e., $K_{st} > 0$)?			
If yes to the above two questions, please conduct a Dust Hazard Analysis			
Combustible Dust Control			
Can a non-combustible dust be used instead?			
Can the dust be substituted with a less hazardous one (e.g., substitute powdered materials with materials in pellets/slurry/paste)?			
Is combustible dust stored in closed containers or packaging when not in use?			
Is smoking prohibited at all workplaces with combustible dust?			
Is a spark detection system installed?			
Are non-sparking tools and equipment used?			
Are dust handling equipment bonded and grounded?			
Are your equipment and process fitted with a dust collector system?			
Is there a dust suppression system to prevent dust from being suspended?			
Is there an explosion suppression system to reduce the potential for a dust explosion?			
Are there explosion isolation devices built into the process lines?			
Is there a pressure relief system to reduce pressure build up?			
Is there a safe work procedure established for work involving combustible dust?			
Are process equipment regularly inspected and maintained?			
Is there a regular housekeeping plan for your workplace?			
Are suitable cleaning methods adopted to prevent dust suspension during cleaning?			
Are workers trained on the hazards of combustible dust and their risk controls?			
Are workers provided with the necessary PPEs, such as fire-retardant clothing and static dissipative safety shoes?			

Annex D — Sample GHS Label

Melamine

Product Identifier

Warning

Signal Word

H312: Harmful in contact with skin.
H317: May cause an allergic skin reaction.
H332: Harmful if inhaled.
H351: Suspected of causing cancer.
exposure.
H361: Suspected of damaging fertility or the unborn child.
H373: May cause damage to organs (Urinary tract) through prolonged or repeated exposure.

Hazard Statements

Prevention
- P202: Do not handle until all safety precautions have been read and understood.
- P260: Do not breathe dust.
- P280: Wear protective gloves/ protective clothing/eye protection/ face protection.

Response
- P308 + P313: If exposed or concerned: Get medical advise/attention.
- P304 + P340: IF INHALED: Remove person to fresh air and keep comfortable for breathing.

Storage
- P405: Store locked up.

Precautionary Statements

Warning: May form explosible dust-air mixture if dispersed.

Keep storage containers tightly closed. Store them in a locked area or in an area accessible only to qualified or authorized persons. For further information on this product, refer to Safety Data Sheet.

Supplementary Information

Melamine International Ltd.

123 ABC Avenue 1	Contact number:	65 6123 1234
ABC Building	Emergency contact number:	65 6456 4567
Singapore 123456		

Supplier Information

* Code numbers for hazard and precautionary statements are optional.
Disclaimer: Label is produced not to scale and with the available known data at the point of print.

Published in July 2025 by the Workplace Safety and Health Council in collaboration with the Ministry of Manpower.

This publication is available on the
Workplace Safety and Health Council
Website: www.wshc.sg