PRIMATECH WHITE PAPER

PROCEDURE FOR DUST HAZARD ANALYSIS (DHA)

Glossary of Terms

Combustible dust: A finely divided combustible particulate solid that presents a flash-fire hazard or explosion hazard when suspended in air or the process-specific oxidizing medium over a range of concentrations. As used in the standard, the term includes powders, fines, fibers, etc.

Combustible particulate solid: Any solid material composed of distinct particles or pieces, regardless of size, shape, or chemical composition, that, when processed, stored, or handled in the facility, has the potential to produce a combustible dust.

Competent igniter: Ignition occurs where sufficient energy per unit of time and volume is applied to a deflagratory particulate suspension. Energy per unit of mass is measured as temperature. When the temperature of the suspension is increased to the auto-ignition temperature, combustion begins. Ignitability is usually characterized by measuring the minimum ignition energy (MIE). The ignition source must provide sufficient energy per unit of time (power) to raise the temperature of the particulate to its autoignition temperature (AIT).

Deflagration: Propagation of a combustion zone at a velocity that is less than the speed of sound in the unreacted medium. The primary concern of the standard is a deflagration that produces a propagating flame front or pressure increase that can cause personnel injuries or the rupture of process equipment or buildings. Usually these deflagrations are produced when the fuel is suspended in the oxidizing medium.

Dust deflagration hazard: A condition that presents the potential for harm or damage to people, property, or the environment due to the combustion of a sufficient quantity of combustible dust suspended in air or another oxidizing medium.

Dust explosion hazard: A dust deflagration hazard in an enclosure that is capable of bursting or rupturing the enclosure due to the development of internal pressure from the deflagration.

Dust hazards analysis (DHA): A systematic review to identify and evaluate the potential fire, flash fire, or explosion hazards associated with the presence of one or more combustible particulate solids in a process or facility.

Explosion: The bursting or rupture of an enclosure or container due to the development of internal pressure from a deflagration.

Fire hazard: Any situation, process, material, or condition that, on the basis of applicable data, can cause a fire or provide a ready fuel supply to augment the spread or intensity of a fire and poses a threat to life or property.

Flash fire: A fire that spreads by means of a flame front moving rapidly through a diffuse fuel, such as dust, gas, or the vapors of an ignitible liquid, without the production of damaging pressure. A flash fire requires an ignition source and an atmosphere containing a flammable gas, a flammable vapor, or finely divided combustible particles (e.g., coal dust or grain) having a concentration sufficient to allow flame propagation. The extent and intensity of a flash fire depend on the size and concentration of the gas, vapor, or dust cloud. When ignited, the flame front expands outward in the form of a fireball. The resulting effect of the fireball's energy with respect to radiant heat significantly enlarges the hazard areas around the point of ignition.

Hybrid mixture: An explosible heterogeneous mixture, comprising flammable gas or vapor with suspended solid or liquid particulates, in which the total flammable gas concentration is ≥10 percent of the lower flammable limit (LFL) and the total suspended particulate concentration is ≥10 percent of the minimum explosible concentration (MEC).

The presence of flammable gases and vapors, even at concentrations less than the lower flammable limit (LFL) of the flammable gases and vapors, adds to the violence of a dust-air combustion. In certain circumstances, hybrid mixtures can be deflagrable, even if the dust is below the MEC and the vapor is below the LFL. Furthermore, dusts determined to be nonignitible by weak ignition sources can sometimes be ignited when part of a hybrid mixture. Examples of hybrid mixtures are a mixture of methane, coal dust, and air or a mixture of gasoline vapor and gasoline droplets in air.

Minimum explosible concentration (MEC): The minimum concentration of a combustible dust suspended in air, measured in mass per unit volume, that will support a deflagration.

Minimum ignition energy (MIE): The lowest capacitive spark energy capable of igniting the most ignition sensitive concentration of a flammable vapor/air mixture or a combustible dust/air mixture as determined by a standard test procedure.
Spark: A moving particle of solid material that emits radiant energy due to either its temperature or the process of combustion on its surface.

Threshold housekeeping dust accumulations: The maximum quantity of dust permitted to be present before cleanup is required.

ABBREVIATIONS

Abbreviation	Meaning
AIT	Autoignition temperature
DHA	Dust hazard analysis
MEC	Minimum explosible concentration
MIE	Minimum ignition energy
NFPA	National Fire Protection Association
OSHA	Occupational Safety and Health Administration
PHA	Process hazard analysis
PPE	Personal protective equipment
PSM	Process safety management
P&ID	Piping and instrumentation drawing

Introduction

NFPA 652-2016, *Standard on the Fundamentals of Combustible Dust*, provides the basic principles of and requirements for identifying and managing the fire and explosion hazards of combustible dusts and particulate solids. The standard is intended to provide the minimum general requirements necessary to manage the fire, flash fire, and explosion hazards posed by combustible dusts and directs the user to other NFPA standards for industry-specific and commodity-specific requirements.

Any time a combustible dust is processed or handled, a potential for deflagration exists. The degree of deflagration hazard varies depending on the type of combustible dust and the processing methods used.

Most dust explosions occur as a series of deflagrations leading to a series of explosions in stages. While a single explosion is possible, it is the exception rather than the rule. Most injuries are the result of the secondary deflagrations rather than the initial event. Most explosion events are a series of deflagrations each causing a portion of the process or facility to explode. Primary deflagrations lead to secondary deflagrations, usually fueled by accumulated fugitive dust that has been suspended by the acoustic impulse waves of the initial, primary deflagration and entrainment by the deflagration pressure front. The majority of property damage and personnel injury is due to the fugitive dust accumulations within the building or process compartment. The elimination of accumulated fugitive dust is critical and the single most important criterion for a safe workplace.

Dust hazard analysis (DHA) is a key requirement of the prescriptive approach to compliance with the standard and it supports the performance-based approach to compliance. The hazards addressed by a DHA are the fire, deflagration, and explosion hazards of combustible dusts. This document describes the requirements relating to DHA and provides a procedure for conducting DHA developed by Primatech.

Pre-Requisites for DHA

The performance of a DHA presupposes that the owner/operator of a facility has determined that:

- The facility manufactures, processes, blends, conveys, re-packages, generates, or handles materials that are combustible dusts or combustible particulate solids.
- The materials are not covered by one of the exemptions in NFPA 652.
- Locations in the process have been determined where a dust cloud sufficient to support a deflagration could occur. Loss records and knowledge of process conditions are used to make this assessment.
- The combustibility and explosibility hazards of the materials have been determined.
- The materials are combustible and/or explosible.
- Properties of the materials needed to support DHA have been characterized.

Scope of DHA

NFPA 652:2016 addresses all phases of the manufacturing, processing, blending, conveying, repackaging, generating, and handling of combustible particulate solids or hybrid mixtures, regardless of concentration or particle size, where the materials present a fire, a flash fire, or an explosion hazard. Thus, the scope of DHA studies must include these items. Abnormal operation also must be addressed. It is possible that a single DHA study may address all these items or multiple studies may be performed.

A DHA is a detailed analysis and documentation of both the process and the building compartment or building housing the process. Pieces of equipment can leak dust into building compartments and buildings. Consequently, each building compartment or building where combustible particulates are being handled or processed is considered for potential deflagration hazard in addition to process equipment.

Leaks always constitute the fines fraction of the particulate being handled. In addition, air movement generally lifts the finest, most hazardous dust highest in the space. So DHA for building compartments and buildings is based on test data for the fine dust that is obtained from the highest locations in the building compartment.

Buildings and building compartments should be evaluated for both deflagration hazard and building rupture and collapse (explosion) hazard.

Key DHA Elements

<u>Overall</u>

The DHA shall include:

- Identification and evaluation of the process or facility areas where fire, flash fire, and explosion hazards exist.
- Where such a hazard exists, identification and evaluation of specific fire and deflagration scenarios shall include the following:
    - Identification of safe operating ranges.
    - Identification of the safeguards that are in place to manage fire, deflagration, and explosion events.
- Recommendations for additional safeguards where warranted, including a plan for implementation.

<u>Material Evaluation</u>

The DHA shall be based on data obtained in accordance with Chapter 5 of NFPA 652:2016 for material that is representative of the dust present.

<u>Process Systems</u>

Each part of the process system where combustible dust is present, or where combustible particulate solids could cause combustible dust to be present, shall be evaluated, and the evaluation shall address:

- Potential intended and unintended combustible dust transport between parts of the process system.

- Potential fugitive combustible dust emissions into a building or building compartments.

- Potential deflagration propagation between parts of the process system.

This includes the process systems and ancillary equipment such as dust collection systems. Where multiple compartments present essentially the same hazard, a single evaluation might be appropriate.

Each part of the process that contains a combustible particulate solid and that can potentially include both of the following conditions shall be considered a fire hazard and shall be documented as such:

- Oxidizing atmosphere

- Credible ignition source

Each part of the process that contains a sufficient quantity of combustible dust to propagate a deflagration and that can potentially include all the following conditions shall be considered a dust deflagration hazard and shall be documented as such:

- Oxidizing atmosphere

- Credible ignition source

- Credible suspension mechanism

<u>Building or Building Compartments</u>

Each building or building compartment where combustible dust is present shall be evaluated. The evaluation shall address:

- Potential combustible dust migration between buildings or building compartments.

- Potential deflagration propagation between buildings or building compartments.

Where multiple buildings or building compartments present essentially the same hazard, a single evaluation is permitted to be conducted as representative of all similar buildings or building compartments.

Each building or building compartment that contains a combustible particulate solid and that can potentially include both of the following conditions shall be considered a fire hazard and shall be documented as such:

- Oxidizing atmosphere
- Credible ignition source

The evaluation of dust deflagration hazard in a building or building compartment shall include a comparison of actual or intended dust accumulation to the threshold housekeeping dust accumulation that would present a potential for flash-fire exposure to personnel or compartment failure due to explosive overpressure.

Threshold housekeeping dust accumulation levels and nonroutine dust accumulation levels (e.g., from a process upset) shall be in accordance with relevant industry-specific or commodity-specific NFPA standards.

Each building or building compartment that contains a sufficient quantity of combustible dust to propagate a deflagration and that can potentially include all of the following conditions shall be considered a dust deflagration hazard and shall be documented as such:

- Oxidizing atmosphere
- Credible ignition source
- Credible suspension mechanism

Methods for DHA Studies

DHA is not necessarily the same as process hazard analysis (PHA) as used in OSHA's process safety management (PSM) standard and is not intended to trigger such a requirement. DHA does not need to comply with OSHA PSM PHA requirements. While DHA can comply with OSHA PSM PHA requirements, other methods can also be used. However, some processes might fall within the scope of the OSHA PSM standard and there could be a legal requirement to comply with that regulation.

NFPA intends DHA practitioners to match the complexity and extent of DHA to the complexity and extent of the facility and its process.

Purpose, Scope and Objectives Statement

A statement of the study purpose, scope and objectives should be prepared and approved.

The study purpose usually is to comply with the requirements of NFPA 652 to conduct a DHA and also any other applicable requirements. The study purpose should identify the type of particulate solids or dusts being studied.

The study scope addresses:

- Process boundaries
- Equipment included
- Procedures
- Control systems
- Utilities and support systems
- Modes of operation
- External events
- Exclusions
- Assumptions

These scope items are similar to those for PHA studies.

The study objectives specify the types of consequences (e.g. people, property, the environment) and the hazards to be addressed (i.e. fire and explosion hazards of combustible dusts and particulate solids).

Information Needed for a DHA Study

Information needed includes:

- Process description
- Process drawings, e.g. PFD, P&ID
- Process and equipment layout, e.g. plot plan
- Electrical classification diagrams
- Hazard test results for combustible materials
- Properties of combustible materials including:
    - Particle size
    - Size distribution
    - Combustibility and explosivity parameters
- Safety Data Sheets (SDS's)
- Reactivity data
- Thermal and chemical stability data
- Equipment specifications
- Safety system specifications
- Operating and maintenance procedures
- Safe upper and lower limits for operating parameters
- Materials of construction
- Material and energy balances

- Past incident reports
- Etc.

Information needs to be current, accurate, and complete.

Note that some of these items may only be conceptually available or not available for a design stage study. Studies using incomplete information will need to be updated by the client when the full information becomes available.

DHA Team

Typically, a team of people performs a DHA. For some processes, this team may have as few as two persons, or for larger and more complex processes, the team might require many more. The team is made up of a variety of people whose background and expertise include familiarity with:

- Process design
- Operations and maintenance
- Process equipment
- Safety systems and their functions
- History of operation (including past incidents)
- Emergency procedures
- Properties of the combustible materials
- Combustible dust safety

The individuals involved in the DHA could include facility operators, engineers, owners, equipment manufacturers, or consultants.

Facilitator Qualifications

NFPA 652 requires that a DHA shall be performed or led by a qualified person. A qualified person is an individual who, by possession of a recognized degree, certificate, professional standing, or skill, and who, by knowledge, training, and experience, has demonstrated the ability to deal with problems related to the subject matter, the work, or the project.

The facilitator of a DHA should be:

- Experienced in team facilitation

- Familiar with conducting a DHA

- Familiar with the fire and explosion hazards of combustible dusts

- Familiar with safeguards for prevention and mitigation of the consequences of combustible dust fires and explosions

Recording DHA Studies

DHA studies should be recorded in a worksheet in a similar way to PHA studies. NFPA does not require any specific format. The following format is suggested:

Banner:

- Part
- Optionally, Sub-part
- Material
- Safe operating ranges
- Deflagrable / explosible?
- Atmosphere?
- Suspension?
- MEC?
- Sources of ignition?

Worksheet:

- Initiating event
- Scenarios
- Consequences
- Safeguards
- Recommendations
- BY

An example of a completed worksheet is provided in Figure 1.

Figure 1. Example of DHA Worksheet.

Part	1. Bulk bag unloading		
Material	Proprietary.		
Safe operating ranges	See SOP for loading		
Deflagrable / explosible?	Yes.	**Atmosphere?**	Yes, air.
Suspension?	Yes.	**MEC?**	Yes.
Sources of ignition?	Yes.		

Initiating Event	Scenario	Consequences	Safeguards	Mitigated Risk			Recommendations	By
				S	L	R		
1. Failure of bulk bag	1.1. Dust cloud created that is ignited by static electricity resulting in a flash fire	1.1.1. Potential injury or fatality	1.1.1.1. ▫ Type B bulk bag used				1.1.1.1. ▫ Procedures should state to verify bulk bag is Type B before unloading.	
			1.1.1.2. ▫ Personnel are protected with PPE (FRC and face shields)					
			1.1.1.3. ▫ System is grounded and bonded					
2. Hopper explosion	2.1. A dust layer is suspended and ignited by the explosion resulting in a secondary explosion in the room	2.1.1. Potential injury or fatality					2.1.1.1. ▫ Install fugitive dust collector near charging station.	
							2.1.1.2. ▫ Ensure fugitive dust is cleaned promptly.	
							2.1.1.3. ▫ Ensure the discharge connection is sufficiently robust to avoid accidental powder releases.	
							2.1.1.4. ▫ Ensure electrical equipment complies with the area classification.	
							2.1.1.5. ▫ Develop a housekeeping program with documentation to prevent hazardous dust accumulation.	

DHA Steps

This approach reflects aspects of the DHA example provide in Appendix B of NFPA 652:2016 as well as aspects of commonly used PHA methods.

Step 1. Identify parts and, optionally, sub-parts of the process system.

Parts include process components, building compartments, and buildings. Sub-parts are divisions of parts.

Each and every process component in which a deflagration could occur should be addressed, including ducts, conveyors, silos, bunkers, vessels, fans, and other pieces of process equipment.

Each and every facility compartment containing combustible particulate solids should be addressed. The complete contents of a compartment should be considered, including hidden areas. As appropriate, compartment areas should be designated as parts.

A descriptive name and identifier should be provided for each part.

NFPA 652:2016 states:

> "Usually a volume exemption of 8 ft3 (0.2 m3) or less is applied to enclosed pieces of process equipment in deflagration hazard management. This exemption comes from the difficulty in designing deflagration suppression for vessels that small, as well as the modest hazard such small vessels represent. Assuming an 8-to-1 volumetric expansion from a dust deflagration, an 8 ft3 (0.2 m3) enclosure will yield a fireball volume of approximately 64 ft3 (1.8 m3), the volume of a sphere with a 10 ft (3 m) diameter. This is the estimated maximum extent of the fireball volume. This fact can be used to select the parts of the process system to be considered in the analysis. If a piece of process equipment includes a volume less than 8 ft3 (0.2 m3), it should be documented as such in the DHA."

Primatech interprets this volume exemption to mean that items of equipment with volume less than 8 cubic feet can be documented as such and not addressed further.

Each part or sub-part is considered in the remaining steps of the procedure.

Step 2. Identify materials posing combustible dust hazards that may be present in the part of the process.

The combustible dusts and particulate solids that are present, or may be present, in the part of the process under consideration are identified and recorded in the DHA worksheet banner.

Step 3. Identify safe operating ranges for the part.

The design intent for each part of the process specifies allowable values or ranges of parameters such as temperature and flow rate to maintain safe operation. These ranges should be specified for relevant parameters.

Step 4. Consider deflagration hazard in the part or sub-part under consideration.

The potential for a dust deflagration should be based on the potential for all necessary and sufficient conditions for a deflagration to exist concurrently at the point of consideration. They are:

1. Presence of a combustible particulate solid of sufficiently small particle size to deflagrate

   Is the particulate deflagrable (explosible)? The ability to propagate a deflagration flame front depends on how much heat is released per unit of mass when it burns and particle size. What are the deflagration properties for the material? Note that particle attrition will increase the fines content.

2. Presence of air or other oxidizing atmosphere.

   Is there an atmosphere that supports combustion?

3. Means of suspending or dispersing the particulate.

   Is the particulate suspended in air or other oxidant? Most large-loss explosions involving combustible dust have occurred because a small event produced an ignition mechanism and a dust dispersion of the accumulated fugitive dust in the interior of a building.

4. A combustion particulate solid suspension of sufficiently high concentration to deflagrate

   Is there sufficient concentration to support a deflagration? If the dust concentration under the range of operating conditions exceeds the MEC of the dust, then there is the potential for flame propagation.

   Is there sufficient fugitive dust accumulation within a building compartment or building to trigger the designation of deflagration hazard or flash-fire hazard in the building interior?

5. Competent source of ignition.
   Are there likely ignition sources? Ignition sources are complex and not always predictable. It is best to assume ignition is possible in all cases. Some situations

of ignition source control could be determined acceptable by performing risk analysis.

Examples of sources are an electrostatic discharge, an electric current arc, a glowing ember, a hot surface, a welding slag, frictional heat, or a flame.

Answers to each question are recorded in the worksheet banner with supporting information.

Step 5. Identify initiating events

The events that may initiate hazard scenarios for the part or sub-part under consideration are identified and recorded in the worksheet. Generally, there may be more than one event for each part or sub-part.

Combustible particulate solids handling processes present a special case regarding initiating events. In many cases an explosible dust cloud may already be present inside a piece of equipment. Ignition is the initiating event. In some cases, a release of dust forming a suspended cloud may be the initiating event. In such cases, the presence of an ignition source is an unplanned event.

Step 6. Identify scenarios

Details of each scenario are recorded in the worksheet. Scenarios endpoints are fires, deflagrations, and explosions.

Step 7. Identify and document consequences.

The predictable consequences are identified using conservative assumptions to yield a credible worst case. The receptors impacted and the extent of the impacts should be identified. Receptors include facility personnel, the public, the facility including processes and equipment, adjacent properties, and the environment. Impacts from both primary and secondary events should be addressed.

Step 8. Identify and document any existing safeguards.

Existing measures that protect against fires and explosions are identified and recorded in the worksheet. Measures such as isolation, segregation, separation, walls, bonding, grounding, and good housekeeping may have been implemented.

Step 9. Identify and document any recommendations.

Recommendations may be made for modified or new safeguards. Also, recommendations may be made to obtain information needed to decide on remedial measures. Usually, options for remedial measures will be found in the relevant industry or commodity-specific NFPA standards (see Annex D of NFPA 652:2016).

Recommendations may result in action items requiring changes to the process materials, physical process, process operations, or facilities associated with the process.

DHA Documentation

The results of the DHA review must be documented, including any necessary action items. A report similar to a PHA report should be prepared. It should contain the worksheets used to record the DHA study.

Follow-on to DHA

These actions should be taken on completing a DHA:

- Develop a plan for implementation of action items. Assign responsibility and due dates for implementing the action items and follow up to ensure their implementation.
- Manage the identified fire, flash fire, and explosion hazards in accordance with paragraph 4.2.4 of NFPA 652.
- Communicate the hazards to affected personnel in accordance with section 9.5 of NFPA 652.