Variables that impact Combustible Powder Explosion Properties

Focus Article

Introduction

“These results can’t be right! You must have tested the wrong sample.” These words have been shared with DEKRA’s laboratory staff several times after a powder was tested in our combustible dust hazard laboratory. Perhaps, previous tests provided by the facility were less explosive. Or a sister site located in a different region had powder that was more difficult to ignite, even though the engineering staff insists the manufacturing process is the same. Or site-specific test results are quite different from what was provided in a literature source.

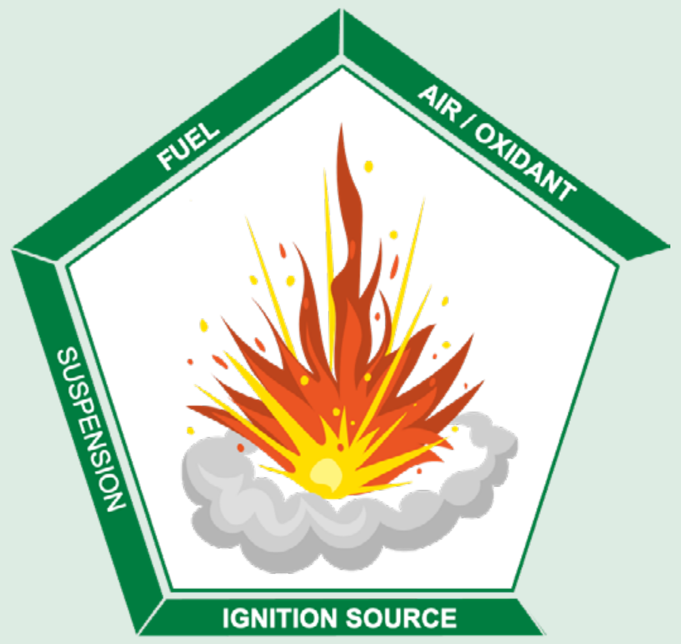
Many facilities know it is important to identify and protect their facilities from combustible dust fire and explosion risks, but they are less aware of the process variables that can impact powder explosion properties. This paper seeks to provide guidance to those involved in dust-explosion prevention and protection to ensure that they test the right materials in the right tests and under the right conditions—and then apply the data in the right way.

Combustible Dust Fundamentals

For an ignition (fire, flash fire, or explosion) to occur, three elements must be present:

(1) a fuel (flammable or combustible material), (2) an oxidizing environment (typically, oxygen present in air), and (3) an ignition source. These elements are commonly referred to as the "fire triangle." If any one of these three elements can be removed,fire cannot be initiated. Combustible powders lying on a surface, typically, exhibit traditional combustion, as long as they remain on the surface.

Fire



Flash Fire (Dust Cloud)

Explosion (Dust Cloud)

Lofting powder into an oxidant (like air) can cause a different fire dynamic and explosive behavior. Suspending combustible dust within an explosible concentration can cause a flash fire (if not within an enclosure) or explosion (if the dust cloud is confined within an enclosure, like a dust collector or a room). A flash fire or explosion caused by these suspended solids can cause significant harm to people and property. This is why facilities sample the powders they use so that they can understand the combustion and explosion characteristics of the materials and ensure that unit operations within the process are designed with adequate controls.

When assessing dust-explosion risks in industrial environments, one challenging—and poorly understood— question is "What should we test?" For liquids and gases, flammability data are, typically, well understood and available in literature. Explosivity data for combustible dusts is more limited because of the complexity of variables that can change fundamental properties of the dust. These variables include particle size, moisture content, and particle morphology. The complexity is compounded when the powder consists of several chemical components.

In order to ensure that a robust basis of safety exists to avoid dust explosions, a facility must have sufficient knowledge of dust characteristics of the powders being stored, produced, and handled. This information can help establish procedural and engineering controls to protect workers, the facility, and first responders from harm. Understanding which variables can impact powder explosibility properties is essential in helping identify which powder samples to test, so information can be used to design a safe process.

Critical Parameters For Dust-Explosion Characterization

The main hazard characteristics of combustible powders can be categorized into five groups: (1) explosion severity, (2) ignition sensitivity, (3) flammable limits, (4) electrostatic properties, and (5) thermal stability. Table 1 summarizes the key data within each group. Not all of these data have to be collected for all products. Once screening testing is complete, an expert can help guide facility staff in implementing a smart test plan that optimizes the number of samples and types of tests that are necessary to obtain data to safely design and operate the process.

When testing and determining these properties, there are variables that can have substantial impact to results. Some of these variables are explained below.

Test Type	Test	Description
Screening for fire and explosion hazards	Go/No-Go classification	Determines if a dispersed powder is explosible (Go) or non-explosible (No-Go). If a Go, more testing is necessary to help establish a design basis of safety for the process.
	Burning rate	Determines if a powder on a surface can sustain combustion and presents a fire/ flammability hazard when lying on a surface.
Explosion severity	Explosion severity analysis using 20 L or 1 m3 sphere	The test generates data for maximum dust explosion pressure (Pmax), dust explosion constant (Kst), and class (St).
Ignition sensitivity	MIE: minimum ignition energy	Minimum spark energy capable of igniting a combustible dust cloud. Two methods exist to account for the differences between electrostatic sparks and mechanical sparks.
	MIT (cloud): minimum (cloud) ignition temperature	Minimum temperature capable of igniting a combustible dust cloud.
	MIT (layer): layer ignition temperature	Minimum surface temperature capable of igniting a dust layer.
Flammable limits	LOC: limiting oxygen for combustion	Lowest atmospheric oxygen concentration in air capable of supporting combustion of the combustible dust cloud.
	MEC: minimum explosive concentration	Minimum concentration of explosible dust in air capable of propagating a dust explosion.
Electrostatic properties	Powder volume resistivity	Resistivity (inverse of conductivity) of the dust — related to the ability of the powder to dissipate any accumulated electrostatic charge.
	Powder charge relaxation time	Direct measurement of the rate at which any electrostatic charge is dissipated. Typically, reported as the time taken for charge to decay to 1/e (37%) of an initial value.
	Powder chargeability	The propensity of the powder to accumulate electrostatic charge (measured under pneumatic transfer conditions) in the air.
Thermal stability properties	Testing depends on process scenarios	Onset temperature of decomposition, or self-reaction, is a parameter that can inform when the dust itself presents an ignition hazard.

Table 1: Hazard Characteristics of Combustible Dusts

1. Particle Size

The particle size distribution of a bulk powder influences dust explosion characteristics. A rule of thumb is that dust explosion propagation occurs with dusts below 500-micron particle size diameter. There are exceptions to this rule, so all powders that can be physically lofted into a cloud should be screened for explosibility to ensure that hazards are identified. Typically, as the median particle diameter reduces below 500 microns, the dust explosion properties of the powder get progressively more energetic.

For any given dust handled in a facility, the particle size will normally be a distribution. There will be a finer portion and a coarser portion. In most cases, the finer portion will have properties that are more energetic when suspended and ignited, while the larger particles will be less energetic, or possibly not explosible.

Figure 1 provides a typical particle size distribution of a sample of chocolate powder. In this case, a portion of the sample is flammable, and a portion is not. The energetic property of the dust varies based on the particle size.

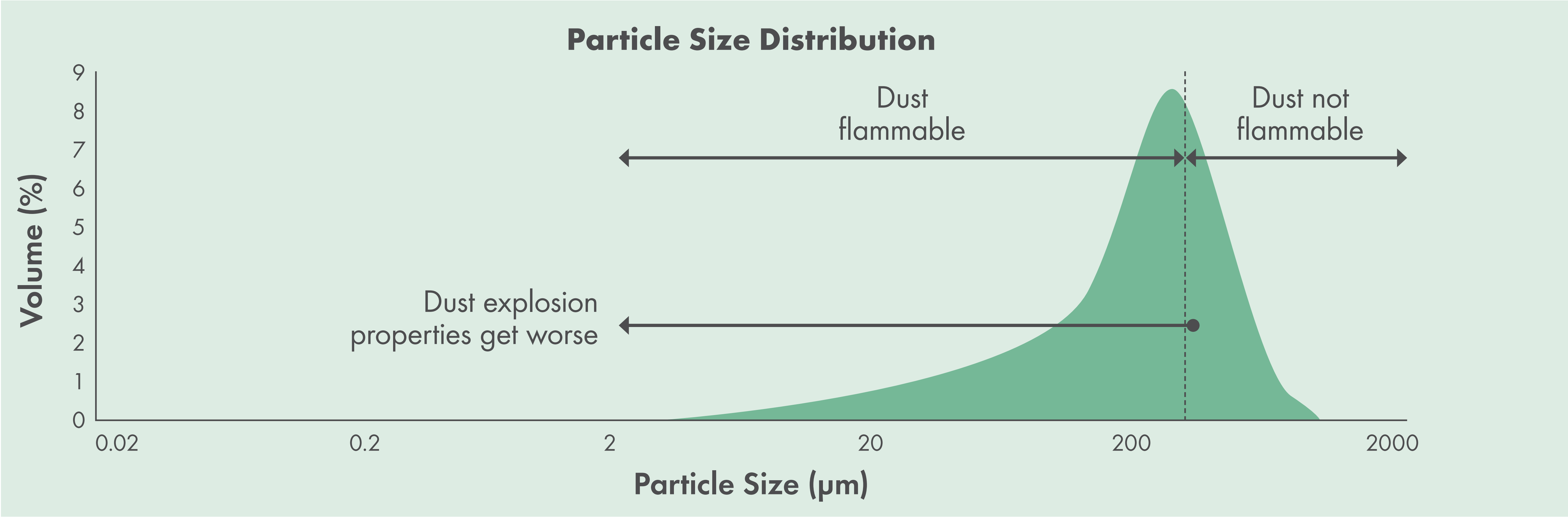


Figure 1: Particle Size Distribution of a Chocolate Powder Sample

In this example, if the chocolate powder sample were tested in the as-received condition with a wide range of particle sizes, the result may lead to erroneous conclusions when the test results are used to design the plant. If there is processing in the facility that leads to sorting the coarser (larger) and fine (smaller) particles from one another, the test results will not reflect the explosive characteristics accurately.

When a dust is dispersed in air, larger particles will fall faster while the fines-rich cloud continues to be suspended. Testing a representative as-received distribution may yield less-energetic results because the larger particles are less explosible. A comprehensive Dust Hazard Analysis (DHA) is needed in order to consider if additional samples (or separating out the coarse particles) are needed so that there is an accurate analysis of the hazards associated with various unit operations in the powder-handling and powder-conveying process. Teams, sometimes, decide to use the finer-is-worse rule of thumb, designing processes based on the explosible properties of the fines within the sample. If they believe that the larger particles will be present in the sample, control measures must be evaluated to ensure that process variability and changes do not result in changes in the sample particle size distribution that could result in a more explosible dust.

One exception to the finer-is-worse rule of thumb is when situations involve nano particles. Often, these particles can behave in unexpected ways. Nanoparticles can start to agglomerate (clump together) and behave as if they were larger particles when dispersed as a cloud. If the facility is using nanoparticles, it will want to construct a smart-testing plan to consider both the larger and finer particles, so they understand the actual explosible characteristics of the powder and how to design and administer controls.

2. Hybrid Mixtures: When Liquids Are Mixed With Powder

2.1 Flammable Solvent

The vapor formed by flammable solvent is easier to ignite, sometimes by orders of magnitude, than many combustible powders. That is why many facilities use the solvent's flammable characteristics as a conservative basis for facility design. If the facility wants to take a less- conservative approach, it is possible to test powder samples that contain solvent, as long as the powder/solvent mixture is dry enough that it can physically be lofted and dispersed into a cloud. Data obtained for such a hybrid mixture may be more energetic than that for the dry powder, making this test important for some facilities. Facilities also may need to assess situations in which a flammable solvent exists in the headspace of closed equipment (e.g., a batch reactor or dryer). A dry powder transferred into the equipment can generate static, thereby creating a potential flash-fire hazard. A risk assessment is required to ensure that appropriate control measures are in place to avoid these scenarios.

2.2 Water

Water is extremely effective at preventing a potentially explosive dust cloud. Moisture content inhibits formation of clouds by causing particle agglomeration. Water can also help reduce electrostatic discharge potential and allow for the bulk material to conduct electricity more easily. Some facilities observe this phenomenon when they notice changes in the relative humidity of the air at the plant.

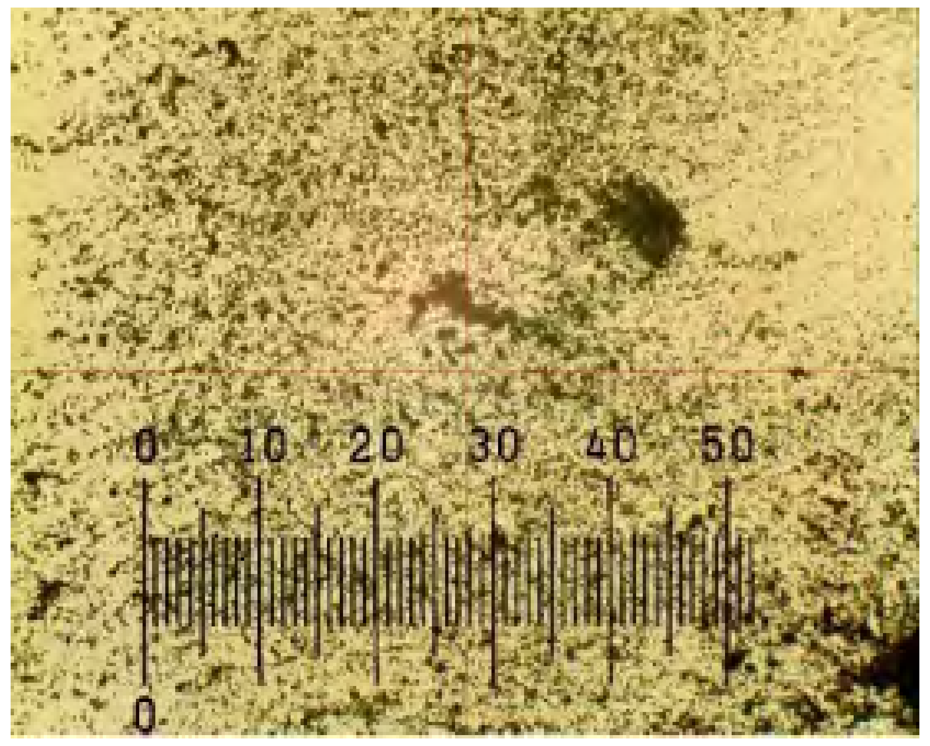
Electrostatic properties can change by orders of magnitude with changing relative humidity conditions (especially if the powder has a hygroscopic nature). There are numerous examples of explosions at low relative humidity, where identical processing at higher humidity yields no such history.

Usually, testing standards propose that less than 5% moisture content within the sample before it is tested. Similar to the particle size analysis, a team needs to conduct a DHA to consider if reliable controls can be put into place to avoid drying out the powder or what moisture content should be considered when selecting a sample for establishing a design basis. There can be areas of plant, or process, operations where the powder mixture has lower moisture content than the sample submitted for analysis. Once that determination is made, a testing specialist can help the facility choose a smart-testing strategy to meet their needs.

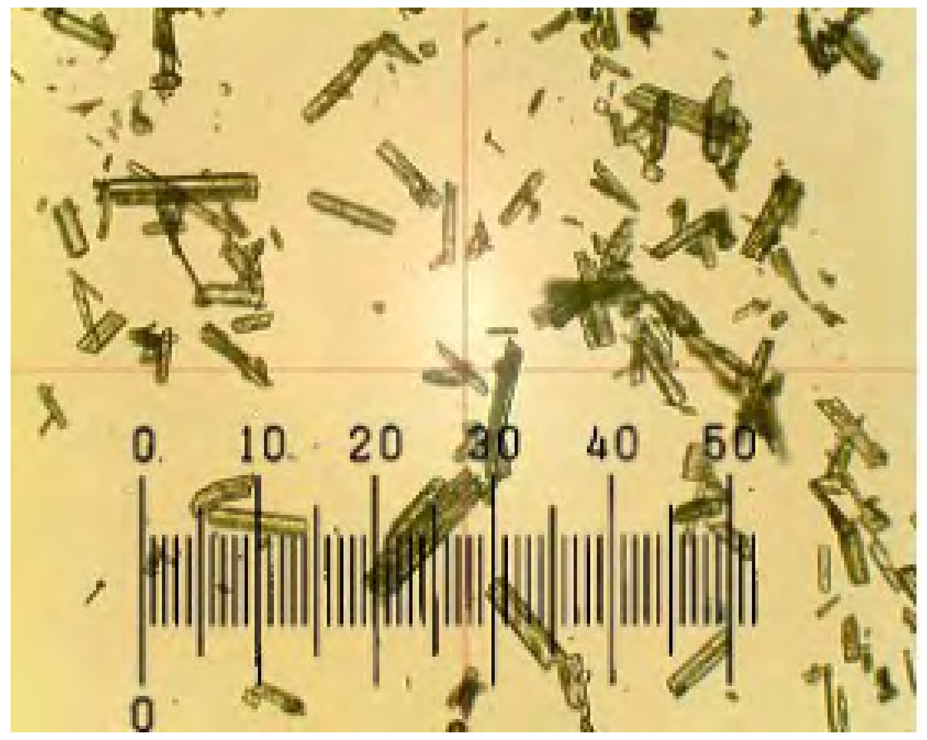
3. Particle Shape (Morphology)

Another aspect that impacts test results is particle shape. Particle morphology can make a substantial difference to explosion properties, such as minimum ignition energy of the sample. A project conducted for a global pharmaceutical company illustrates this point. A process was conducted in two locations, yielding a chemically identical dust. The only difference in the processing method was the crystallization step. This led to two different particle morphology profiles—a needle particle shape and the other yielding an amorphous shape. Even though the particle size distributions were similar, the test results were startlingly different.

Material from Location B required much more stringent electrostatic precautions than the relative insensitive material produced in Location A—even though the materials were chemically identical and exhibited the same (residual) moisture content and broadly similar particle size distributions.



Particles produced in Location A.



Particles produced in Location B.

Variable	Location A Material	Location B Material
Particle size (d50; µm)	32.1	19.1
Moisture content (% w/w)	1.5	1.5
MIE (mJ)	40-50	3-4

4. Other Process Variables

Environmental temperature also alters data, although it has varying impact on explosion properties. For example, increasing temperature can more easily ignite the lofted powder (lower the minimum ignition energy). Increasing process pressure proportionally increases the severity of the explosion. Increasing the oxidant concentration in the headspace of closed equipment (e.g., oxygen-rich atmospheres) will also make it easier to ignite most dusts. When applying data obtained at ambient temperature, mathematical correction of data to account for environmental temperature and initial pressure changes should be performed, if possible. In some cases, testing under the specific conditions are required to generate reliable data, as mathematical correlations do not exist. A multidisciplinary DHA team should collaborate with a testing specialist when they believe they have situations where corrections should be made.

Conclusion

What does this mean for facilities that handle combustible dust?
First, sample and test site-specific or as-received powders. Literature data, where it exists, will rarely replicate the particle size, moisture content, and particle morphology of what is used at the site. For these reasons, many facilities, insurance companies, and authorities ask that site-specific or as-received powders be tested.

Next, assemble a multidisciplinary team to review the sampling and test plan for the facility. It may be appropriate to test the finest fraction of a dust sample to ensure a robust design. The plant may need to explain what it understands about the moisture or solvent content of the powders during processing. The team will also want to discuss where bulk material can have different particle shapes, either due to changes in suppliers or process changes chemical, crystallization, or size-reduction process unit operations. The team will also want to consider process temperatures, pressures, and oxidant concentrations that may impact dust explosibility data.

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- Support the implementation, monitoring, and sustainability of PSM programs
- Audit existing PSM programs, comparing with best practices around the world
- Correct and improve deficient programs

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- Flammability/combustibility properties of dusts, gases, vapors, mists, and hybrid atmospheres
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- Thermal instability (DSC, DTA, and powder specific tests)
- Energetic materials, explosives, propellants, pyrotechnics to DOT, UN, etc. protocols
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- Electrostatic testing for powders, liquids, process equipment, liners, shoes, FIBCs

Specialist Consulting (Technical/Engineering)

- Dust, gas, and vapor flash fire and explosion hazards
- Electrostatic hazards, problems, and applications
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- Hazardous area classification
- Mechanical equipment ignition risk assessment
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