Designing your dust collection system to meet NFPA standards — Part I

About 40 percent of combustible dust explosions reported in the US and Europe over the last 25 years have involved dust collectors. Dust collection systems are now a primary focus of inspections required by OSHA’s National Emphasis Program on safely handling combustible dusts.1 OSHA also has the authority to enforce National Fire Protection Association (NFPA) standards for preventing or protecting against dust explosions. This two-part article focuses on how you can design your dust collection system’s dust collector, ductwork, and exhaust fan to meet the intent of these NFPA requirements. Part II will appear in January.

The explosion hazards posed by dusts commonly handled in bulk solids plants can be surprising. In fact, most natural or synthetic organic dusts and some metal dusts can explode under the right conditions. You can find a limited list of combustible dusts and their explosion data in the appendix to the NFPA standard focusing on dust explosion hazards, NFPA 68: Standard on Explosion Protection by Deflagration Venting (2007),2 and in Rolf K. Eckhoff’s book Dust Explosions in the Process Industries.3

While such published data can give you some idea of your dust’s explosion hazards, using this data for designing explosion prevention or protection equipment for your dust isn’t recommended. Your processing conditions and your dust’s characteristics — such as its particle size distribution — differ from those for the published data for the same material, producing different combustible dust results. The only way to determine your dust’s combustibility is to have a qualified laboratory run explosion tests on a representative sample of the dust. Then, to meet NFPA requirements, you’ll need to commission a hazard analysis of your dust collection system to document that its design mitigates the explosion risk posed by your dust. (For more information, see reference 4.)

Some dust explosion basics

The five elements required for a dust explosion can be pictured as a pentagon, as shown in Figure 1. The three elements labeled in black are those in the familiar fire triangle: fuel (combustible dust), an ignition source, and oxygen. The remaining two elements — dust dispersion at or greater than dust’s minimum exploitable concentration (MEC) and confinement of the dust cloud in equipment or building — are unique to dust explosions.
dust's minimum explosible concentration (the lowest dust concentration that will propagate a combustible dust deflagration or explosion; MEC) and confinement of the dust cloud within equipment or a building.

Put simply, a dust explosion occurs when an ignition source touches a dust cloud with a concentration at or greater than the dust's MEC. A dust cloud with this concentration can result when a layer of dust thicker than ½ inch on equipment, piping, overhead conduit, or similar components is pushed into the air by some event, such as the pressure wave from a relief device's operation. When an ignition source — such as a spark or the flame front from an equipment explosion — touches the cloud, the dust can explode with devastating impact, as evidenced by the fatal results of the sugar refinery explosion in Georgia last February. To mitigate your dust collection system’s explosion risk, you need to focus on preventing dust accumulation in the system, preventing ignition, and providing explosion prevention or protection at the collector — all covered by NFPA standards.

Even when a dust collector is equipped with an explosion vent that works properly, the ductwork in the dust collection system can propagate a collector dust explosion throughout a process area. An investigation into one such case revealed that a contributing factor was the ignition and explosion of dust that had accumulated in the ductwork because of the system’s inadequate conveying velocity. Another contributing factor was the lack of flame-front-isolation devices in the collector’s dirty-air inlet and the clean-air outlet for recirculating air to the building. Such devices could have prevented the flame front in the collector from entering the inlet duct and re-entering the building through the outlet duct.

In this case as in many others, following the requirements in NFPA standards for mitigating explosion risks in a dust collection system could have prevented the dust explosion from propagating beyond the dust collector. In the following sections, we’ll look at how you can design your dust collection system to meet the NFPA standards. Information covers preventing dust accumulation in ductwork, eliminating ignition sources, and using explosion prevention and protection methods at the collector. [Editor's note: Capture hood design, another important factor in designing a safe dust collection system, is beyond this article’s scope; for more information, see the later section “For further reading” or contact the author.]

Preventing dust accumulation in ductwork

To prevent dust from accumulating in your dust collection system’s ductwork and becoming fuel for an explosion, you must design all ducts in the system with two principles in mind, as described in NFPA 654: Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids (2006). First, the conveying air velocity must be adequate throughout the duct. Second, at points where two airstreams merge, the duct sections must join in a way that maintains this velocity.

If your plant handles a combustible dust, a visiting OSHA inspector will ask whether the conveying air velocity through your dust collection system is adequate — and will ask you to prove it. Why is this velocity important? Keeping the conveying air velocity in every part of the duct within a reasonable range will prevent two problems: Too low an air velocity will cause the dust to drop out of the air and build up inside the duct, and, depending on the dust’s characteristics, too high an air velocity will waste energy, erode the duct, or, if the dust is moist or sticky, cause the dust to smear on the duct wall.

A conveying air velocity between 3,500 and 4,000 fpm (17.5 and 20 m/s) is a reasonable starting point for designing your system. Then, based on supporting data about your application, you can speed or slow the conveying air to the system’s optimal velocity. For instance, if your system handles an extremely fine, lightweight material that won’t clump together, like cotton dust, you can slow the velocity to 3,000 fpm; if you handle a very heavy material, like lead dust, you may need to increase the velocity to 4,500 to 5,000 fpm. For guidance in determining the optimal velocity for your application, see Table 5-1 in the American Conference of Governmental Industrial Hygienists’ Industrial Ventilation: A Manual of Recommended Practice for Design (26th edition, 2007), which lists minimum duct design air velocities for many dusts.

How duct sections are joined in your system also affects the conveying air velocity. If incorrectly designed, the point where ducts join to merge two airstreams can slow the air velocity, in turn causing the dust to drop out and accumulate in the duct. You can prevent this problem by connecting each branch duct to a 15-degree tapered expansion on the main duct, which enlarges the main duct diameter to a size appropriate for the merged airstreams. A related problem is that dust particles can drop out of the airstream when a branch duct joins the main duct at too great an angle. The momentum of the conveyed dust particles causes them to want to move in a straight line, so when one duct joins another at a sharp angle, the particles have to
change direction and slow down. Avoid this problem by designing the branch duct entry with no more than a 30-degree angle to the main duct.

Failing to practice these duct design principles can lead to any of several problems that produce a slower-than-required conveying air velocity in your ducts. Following are some visual clues that indicate the air velocity in the ducts isn’t high enough to prevent dust from dropping out of the air. Under each clue, ways to remedy the problem and get adequate conveying air velocity though the ducts are described.

**Clue 1: Main duct diameter doesn’t enlarge after branch junctions.** In Figure 2a, two 8-inch-diameter branch ducts join an 8-inch-diameter main duct, and the main duct’s downstream diameter is the same after each junction. At A, before the first branch junction, the 4,200-fpm air velocity required to convey the dust is reasonable and can be achieved by the system’s design air velocity of 1,500 cfm. But because the duct diameter doesn’t enlarge after the branch junctions, the required air velocity increases exponentially: It’s 8,400 fpm at B, after the first branch junction, which would require a 3,000-cfm airflow, and it’s 16,800 fpm at C, after the second junction, which would require a 4,500-cfm airflow. However, 5,500 fpm is the practical upper limit for air velocity in system ductwork. To meet the velocity requirements in this duct arrangement, the system would require a major upgrade of the exhaust fan and electric power, which is impractical.

**Solution:** The more economical solution is to enlarge the downstream duct. This will solve the problem that results from not upgrading the exhaust fan — that is, that C gets most of the airflow, B gets some, and A gets very little. To ensure that the duct’s diameter is large enough after a branch duct joins it, follow this rule of thumb: The sum of the areas of the upstream branch ducts should roughly equal the area of the downstream duct. Based on the equation duct area = \( \pi \times \left( \frac{\text{diameter}}{2} \right)^2 \), this rule can be restated as: the sum of the squares of the upstream branch duct diameters should roughly approximate the square of the downstream main duct diameter. Thus, at B:

\[ 8^2 + 8^2 = 128 \quad \text{or} \quad 121 \]

so the main duct diameter at B should be changed to 11 inches. Then, at C, two solutions are possible:

\[ 11^2 + 8^2 = 185 \quad \text{or} \quad 13^2 \]
\[ 11^2 + 8^2 = 185 \quad \text{or} \quad 14^2 \]

so the main duct diameter at C should be changed to 13 or 14 inches, depending on your application’s conveying velocity requirements.

**Clue 2: Main duct is blanked off.** In Figure 2b, an 8-inch-diameter main duct, A, is blanked off. A 4-inch-diameter branch duct, B, joins the main duct at a 90-degree angle, forming a T junction. The system’s design airflow at A (4,200 fpm [1,500-cfm airflow]), B (3,900 fpm [350-cfm airflow]), and C (4,100 fpm [1,850-cfm airflow]). But with A blanked off, the required air velocity through the 4-inch-diameter duct (B) is now 3,900 fpm (350-cfm airflow). The exhaust fan might be able to pull an airflow of no more than 600 cfm through B and C, which would drop the air velocity at C from the required 4,100 fpm to 270 fpm.

**Solutions:** Two solutions are possible: You can replace all the duct between B and the system’s dust collector with a smaller duct to achieve an adequate conveying velocity. Or, as a much cheaper alternative, you can remove the blank flange and replace it with an orifice plate that delivers 1,500-cfm airflow at the system’s available static pressure; the orifice plate has a hole at its center that’s sized to meet the system’s airflow and pressure drop requirements.

**Clue 3: Poor duct junctions don’t maintain conveying velocity.** Let’s look at two examples of this problem. In the first, shown in Figure 2c, an 8-inch-diameter duct section abruptly joins a 20-inch-diameter section. At the system’s 1,400-cfm design airflow, the conveying air velocity is 4,000 fpm in the 8-inch section, but it drops abruptly to 650 fpm in the 20-inch section, which will cause the dust to drop out of the air. **Solution:** In this case, the solution is to replace the 20-inch duct section with 8-inch duct. The duct diameter should stay at 8 inches until the next branch junction; after that junction, the duct should be enlarged to maintain the air velocity, following the rule of thumb under Clue 1.

Another poor duct junction is shown in Figure 2d. Here, an 8-inch-diameter branch duct, A, joins an 8-inch-diameter main duct at a 90-degree angle, forming a T junction. The system’s 1,400-cfm design airflow can produce the required 4,000-fpm conveying air velocity through A and section B upstream from the junction without a problem. But section C downstream from the junction would require 8,000 fpm (at an airflow of 2,800 cfm) to convey the dust through the duct and past the T junction. Meeting this impossibly high air velocity requirement would demand an unreasonably high fan energy, and the duct at both B and C would probably plug with dust. **Solution:** In this case, replacing the T junction with a 30-degree Y junction that enlarges to a downstream diameter of 11 inches (again following the rule of thumb in Clue 1) will maintain the system’s 4,000-fpm conveying air velocity.

**Clue 4: Ductwork includes too much flexible hose.** In Figure 2e, flexible hose has been used in place of metal duct as a quick way to connect two duct sections. However, dust builds up more easily on the hose’s corrugated inside surface than on smooth metal duct. The hose’s internal resistance also is more than twice that of smooth metal.
duct, so with the hose bends acting as elbows, the hose’s equivalent length is much greater than its actual length. The system’s exhaust fan may not be large enough to pro-

vide the speed necessary to overcome this additional airflow resistance, and the result is low air velocity that causes dust to drop out of the air and plug the ducts.

Figure 2

Visual clues to duct problems that cause dust accumulation

a. Main duct diameter doesn’t enlarge after branch junctions

b. Main duct is blanked off

c. Smaller-diameter duct abruptly joins larger-diameter duct

d. Branch duct joins main duct at T junction

e. Ductwork includes too much flexible hose

f. Duct blast gate isn’t locked in position
**Solution:** Replace the flexible hose with sections of metal duct that are clamped together. You should use flexible hose in the system only with equipment that must move, such as connecting metal duct to the capture hood for a loss-in-weight feeder that rests on load cells; see NFPA 654 for more information.

**Clue 5: Duct blast gate isn’t locked in position.** Blast gates in ducts add artificial airflow resistance to balance the airflow in individual duct branches. For each blast gate, only one position is correct to balance the airflow in all branches. In Figure 2f, the blast gate has been adjusted to send more airflow into this branch, which steals airflow from other branches.

**Solution:** Set this and other duct blast gates to meet the system’s design airflow and then lock the gates in place. You can avoid this problem altogether by designing the dust collection system for the correct airflow balance without using blast gates, which is called *balance by design*.

**Clue 6: The pressure drop across the filter media is higher than the design pressure drop.** Figure 3 shows the airflow resistance increasing in a baghouse dust collection system in which the pressure drop across the bag filter media exceeds the design pressure drop. (Pressure drop, or *differential pressure*, is the difference in the static pressures measured on the clean and dirty sides of the dust collector; the more dust collected on the filters, the higher the pressure drop will be.) In Figure 3, the design pressure drop across the bag filters is the system’s design static pressure drop.

![Figure 3](image-url)

**Figure 3**

*Effect on airflow of high pressure drop across the filter media*

- **High pressure drop shifts fan operation curve to left**
- **System operating point**
- **Design static pressure to move air from longest duct branch to baghouse inlet**
- **Exhaust fan operation**

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*Airflow (in actual cubic feet per minute)*

*Static pressure (in inches water column)*

- **Design static pressure**
- **11**
- **7**

**Q2**

**Q1**
pressure (11 inches water column) minus the static pressure required to move the air from the longest branch duct to the baghouse inlet (7 inches), which equals 4 inches water column. The line $Q_1$ represents the design airflow the fan should deliver, with the line’s top white portion representing the design pressure drop through the media. But $Q_2$ represents the airflow the fan actually delivers, which is lower than the design level because the actual pressure drop through the media (shown by the line’s white portion) exceeds the design level, increasing airflow resistance.

The system exhaust fan’s operating curve shows how much air the fan can move (airflow, represented by the horizontal axis) at different static pressures (on the vertical axis). As you can see, this curve shifts to the left of the system operating point — showing that the fan delivers less airflow than the system requires — because the higher pressure drop has increased the airflow resistance across the system. Because the fan can’t deliver the required airflow, the conveying air velocity in the ductwork slows and leads to more dust dropping out in the ducts.

**Solutions:** The solution to high pressure drop across the media depends on your application. Assuming you’ve selected the right air-to-cloth ratio (the airflow in cubic feet per minute divided by the square feet of filter media surface area) for your dust collector, properly starting up the collector when the new filters are installed will provide the best long-term performance. Once the new filters are installed, you should also condition them (also called pre-coating or seeding) before your dust collection system goes back online; this will build up an initial dust cake on the media that resists blinding and prevents high pressure drop. (For more information, see reference 7.) With older filters, increasing the cleaning frequency or replacing the filters more often can control the pressure drop across the media. Another solution is to replace your filters with ones that have a larger surface area to better handle your dust-laden airflow.

**Clue 7: Dust cloud is first sign of trouble.** Figure 4 shows a dust cloud surrounding a vibrating conveyor that delivers powder to a sifter; the cloud has developed because the capture hood over the equipment isn’t drawing the dust-laden air into the dust collection system. The dust cloud — a potential explosion hazard — could be the result of duct plugging, filter blinding, or other problems, any of which could reduce airflow through the system. Unfortunately, this dust cloud is the first sign of trouble because the dust collection system pressure, airflow, and other data aren’t monitored.

**Solution:** You need to make routine measurements of static pressure and airflow at appropriate points in the dust collection system, as well as measure each capture hood’s face velocity (the air velocity at the inlet opening). Such system monitoring will reveal any changes in pressure, airflow, or face velocity from the system’s baseline performance data. By helping you spot such changes early, monitoring allows you to catch a small problem before it can create a hazardous dust cloud in your process area.

What is baseline performance data? It’s documented proof of your dust collection system’s performance at startup (or after any significant system modification), which demonstrates that the system can deliver the design airflow at every capture hood or other dust-controlled opening. This is one of the requirements of NFPA 91: Standard for Exhaust Systems for Air Conveying of Vapors, Gases, Mists, and Noncombustible Particulate Solids (2004), which is incorporated by reference into NFPA 654. In addition to verifying the system design, the baseline data provides a reference point for system monitoring. Baseline data documentation is powerful evidence to show an OSHA inspector that your system has adequate conveying velocities. The design documentation you should keep on file includes the system schematic, a table listing locations and dimensions of air-balancing devices (such as blast gates), the as-built system’s static pressure balance calculations for sizing the exhaust fan, and the design bases and specifications for system equipment. (For more information, see reference 8.) Turning the baseline performance data over to the operators once the system is online allows them to use the data to monitor system performance and keep the system working over the long term.

In some cases, comparing this baseline data to current operating data may help you determine that the original system design can no longer handle your application’s changed field conditions and requirements. In this case, you’ll have to redesign the system to meet the new requirements. Several situations requiring you to test the dust collection system to demonstrate that it works as designed are listed in NFPA 91.

**Next month:** In Part II, sections will cover how to eliminate ignition sources in the system and how to use explosion pre-
vention and protection methods at the collector. A final section will explain how to meet additional NFPA requirements.

References


4. Lee Morgan and Terry Supine, “Five ways the new explosion venting requirements for dust collectors affect you,” Powder and Bulk Engineering, July 2008, pages 42-49; see “For further reading” for information on purchasing a copy of this article.


6. Available from American Conference of Governmental Industrial Hygienists, 1330 Kemper Meadow Drive, Cincinnati, OH 45240; 513-742-6163, fax 513-742-3355 (www.acgih.org, mail@acgih.org).

7. Ed Ravert, “Precoating new filters for better airflow, longer filter life,” Powder and Bulk Engineering, October 2006, pages 27-33; see “For further reading” for information on purchasing a copy of this article.

8. Gary Q. Johnson, “Dust control system design: Allowing for your range of process conditions and establishing baseline performance values,” Powder and Bulk Engineering, October 2005, pages 39-48; see “For further reading” for information on purchasing a copy of this article.

For further reading

Find more information on designing dust collection systems and preventing dust explosions in articles listed under “Dust collection and dust control” and “Safety” in Powder and Bulk Engineering’s comprehensive article index (later in this issue and at PBE’s Web site, www.powderbulk.com) and in books available on the Web site at the PBE Bookstore. You can also purchase copies of past PBE articles at www.powderbulk.com.

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