Many bulk solids manufacturing plants use power boilers for electricity generation, which generates fine particles called fly ash. This article discusses the explosive characteristics of fly ash and fly ash recovery systems and describes how to safely handle fly ash in your plant.

For many large-scale industrial manufacturers, using the local power grid to supply the electricity required to operate a manufacturing plant isn’t economical or practical. Plants are frequently located in remote regions where a local power grid may not even exist. To improve reliability, decrease costs, and make locating plants in remote locations possible, manufacturers often generate their own power, commonly by using a power boiler.

A power boiler burns a fuel source, such as pulverized coal, biomass, or natural gas, to convert water into high-pressure steam that’s used to generate consumable electricity. To continuously generate power, the combustion reaction must proceed without interruption, so fresh, oxygen-rich air is continuously pumped along with the fuel into the boiler’s reactor, and combustion exhaust gas (known as flue gas) is simultaneously pumped out.

This flue gas is comprised mostly of nitrogen and carbon dioxide but also contains a small percentage of fine particles known as fly ash. The gases in the flue gas are exhausted to the atmosphere, but only after the fly ash is separated from the gas stream, typically using an electrostatic precipitator (ESP). The details of how an ESP works are beyond the scope of this article, but after separation, the fly ash enters the fly ash recovery system, which typically conveys the material to a storage vessel called a load-out silo.

Depending on the circumstances, fly ash may exhibit explosive properties that can put factory workers and equipment at risk. The hazards of fly ash and fly ash recovery systems are often overlooked, however. This article will discuss the combustible dust hazards associated with fly ash recovery systems in industrial manufacturing plants and explain how to protect your plant from these hazards. Before discussing fly ash recovery systems, it’s important to understand some basics about combustible dust in general (and fly ash in particular).

Combustible dust basics

Any material that can burn has the potential to explode in dust form under the right circumstances. Those circumstances are defined by the combustible dust pentagon, as shown in Figure 1. For a dust explosion to occur, all five elements of the pentagon must be present — fuel, oxygen, ignition, dispersion, and confinement.

Figure 1

Dust explosion pentagon
For example, if you introduce an open flame to a 1-kilogram pile of a known combustible dust (such as sugar), the sugar may burn and smolder for 10 minutes or so, but it won’t explode because only three elements of the pentagon are present — fuel, oxygen, and ignition. However, if you process that same kilogram of sugar dust through a hammermill that pneumatically feeds into a filter receiver, you now have four elements of the pentagon — fuel, oxygen, dispersion, and confinement. Now, if an ignition source, such as a piece of hot tramp metal, passes through the hammermill and enters the downstream filter receiver, the pentagon is complete, and that same mass of sugar dust can explode in milliseconds.

This instantaneous energy release occurs because the material is finely divided (with a high surface-area-to-mass ratio) and suspended in the air. This allows the entire mass of material to oxidize simultaneously, which can generate potentially dangerous levels of heat, flame, and pressure and cause the enclosure to explode.

To determine your dust’s explosion properties, have your equipment supplier or an independent lab test and create a hazard profile for your material. For fly ash generated by a power boiler, the pertinent dust explosion properties are the material’s maximum explosion pressure ($P_{\text{max}}$), maximum rate of pressure rise ($K_{\text{st}}$), minimum ignition energy (MIE), and minimum explosive concentration (MEC). $P_{\text{max}}$ and $K_{\text{st}}$ provide quantitative measures of an explosion’s intensity once a dust cloud is ignited, while MIE and MEC provide quantitative measures of how sensitive the dust is to ignition. Both explosion intensity and ignition sensitivity are important when evaluating your dust explosion risk and designing specific explosion-protection solutions.

A material’s $P_{\text{max}}$ and $K_{\text{st}}$ values are determined by following ASTM testing protocol E1226, using either a 20-liter sphere or 1-cubic-meter test vessel. $P_{\text{max}}$ is a measure of the maximum pressure a dust can create when ignited in the test vessel and is typically expressed in units of bar gauge (barg). $K_{\text{st}}$ is a measure of how quickly the explosion will reach that maximum pressure and is expressed as a change in pressure over time (\(\text{d}P/\text{d}t\)), with the typical unit of measure being bar meters per second (bar*m/s). $K_{\text{st}}$ is also often referred to as the dust’s “deflagration index.” The higher these two values, the more dangerous the dust is considered to be. Combined, $P_{\text{max}}$ and $K_{\text{st}}$ comprise the dust’s post-ignition hazard profile and are specifically used for determining appropriate explosion mitigation methods, such as explosion vents or chemical suppression.

A material’s MIE is a measure of the minimum amount of energy required to ignite a dust cloud. MIE is determined by following ASTM testing protocol E2019 and is typically expressed as a range in millijoules. The lower the dust’s MIE value, the less energy required to ignite the dust cloud and create an explosion. A material’s MEC is a measure of the minimum concentration of suspended dust required to sustain a combustion reaction and is determined by following the ASTM 1515 testing protocol. MEC is typically expressed in units of grams per cubic meter (g/m³). MIE and MEC are primarily used for determining appropriate explosion prevention measures, such as ignition source control or housekeeping.

The sugar dust in the example discussed earlier exploded because the suspended dust cloud inside the filter receiver was ignited by a piece of heated tramp metal that passed through the mill. Because sugar is one of the most studied combustible dusts, we know that its explosion properties are:

- $P_{\text{max}} = 8.5$ barg
- $K_{\text{st}} = 138$ bar*m/s
- MIE = 50 to 100 millijoules
- MEC = 125 g/m³

Applying these properties, we know that an explosion will only occur if the concentration of suspended sugar dust inside the filter receiver is at least 125 g/m³ and the piece of tramp metal contains at least 50 to 100 millijoules of heat energy. We also know that the filter receiver should include explosion mitigation technology designed to protect against a $P_{\text{max}}$ of 8.5 barg and a $K_{\text{st}}$ of 138 bar*m/s.

**Fly ash properties**

Manufacturers strictly scrutinize bulk solid production materials because ingredient quality directly affects the final product. For example, the moisture content and particle size distribution of sugar used for cereal production or the molecular weight of polyethylene used for plastic cup production are carefully monitored because the quality of the final products depends on these variables being within specifications.

Fly ash exhausted from a plant’s power boiler, however, doesn’t affect the quality of the product being manufactured at the plant. Unless the fly ash is being sold as a precursor for cement production, it’s generally discarded as waste. In either case, plant operators pay very little attention to fly ash production, so variations can go undetected from plant to plant, boiler to boiler, or even from batch to batch within the same boiler. These variations can greatly affect the material’s combustibility, but the laissez-faire approach to processing fly ash can create a false impression that the material is harmless. Ensuring
plant safety, however, requires that workers fully understand and respect the combustible dust hazards associated with handling fly ash.

The fuel being burned in a power boiler directly affects the chemical composition of the resulting fly ash. For instance, lignite coal will produce fly ash that differs in appearance and mineralogy from fly ash produced by subbituminous coal. This is also true for fly ash produced by burning pulverized coal versus wood.

Boiler performance also directly influences the physical and chemical properties of the fly ash produced. Boiler performance can be affected by the number of passes through the boiler, the fuel makes, incompatibility between the burner and the boiler, the repeatability of the air-fuel mixture control, and boiler geometry. The most important property that these factors can influence is the fly ash’s loss on ignition (LOI).

LOI is a measure of the fly ash’s residual, unreacted carbon content after the fuel’s primary combustion reaction. This residual carbon content can make fly ash combustible because the dust still has the potential to oxidize. Fly ash is primarily made up of inorganic combustion by-products, including silicon dioxide (SiO₂), aluminum oxide (Al₂O₃), and iron (III) oxide (Fe₂O₃), which pose no explosion risk because they’re already oxidized. However, fly ash with an LOI in the range of 6 to 10 percent by mass still has enough unoxidized carbon content to be explosive. This explosive potential is what makes monitoring and controlling fly ash production an important part of dealing with your plant’s combustible dust hazards.

Because this article is concerned with explosion protection, we’ll assume that all fly ash discussed here is combustible, with an LOI of at least 6 to 10 percent by mass. Lab tests have shown that we can approximate the explosion properties of such fly ash to be:

- \( P_{\text{max}} = 7.0 \text{ barg} \)
- \( K_\text{g} = 100 \text{ bar*m/s} \)
- \( \text{MIE} > 1,000 \text{ millijoules} \)
- \( \text{MEC} = 100 \text{ g/m}^3 \)

You should only reference these properties for the purposes of this discussion, however, since fly ash properties can vary, as discussed earlier.

Other important characteristics that affect the fly ash’s explosion risk are moisture content, bulk density, and particle size distribution. Fly ash typically has a moisture content below 1 percent, a bulk density of 2.5 g/cm³, and a median particle size of 10 microns. Because of the low moisture content and small particle size compared to other common combustible dusts, fly ash easily becomes entrained in air and can remain airborne for some time before settling to form a layer on surfaces. Based on \( P_{\text{max}} \) and \( K_\text{g} \) values, a fly ash explosion will be moderately intense compared to other common combustible dusts but can be more dangerous because of the material’s propensity to become and remain airborne.

Identifying hazards in your fly ash recovery system

Now that we’ve established that fly ash can present combustible dust hazards, the next step is to identify where those hazards are likely to exist in your fly ash recovery system. The recovery system includes all equipment handling the fly ash after the ESP separates the dust from the boiler’s flue-gas stream. Because each application is different, each fly-ash recovery system will vary, but the general purpose is typically the same: The system conveys the fly ash from the ESP discharge to a load-out silo. The fly ash can be conveyed either pneumatically or mechanically. While mechanical conveying is more common, each method has pros and cons.

A typical pneumatic fly ash recovery system is shown in Figure 2a. As the figure shows, the fly ash flows from ESP hoppers through rotary airlocks into a pneumatic conveying line that conveys the fly ash into an intermediate filter receiver. From the filter receiver, the fly ash discharges into the load-out silo through a rotary airlock. The filtered conveying air discharges from the filter receiver and typically recirculates back into the process.

This type of recovery system creates dust explosion hazards inside both the intermediate filter receiver and the load-out silo since the conditions inside both vessels typically meet the dust explosion pentagon’s requirements during normal operation. Also, because the system transfers the fly ash from the ESP within a short time of the material being exhausted from the boiler, the fly ash may still be hot enough when it reaches the filter receiver to cause ignition.

In a mechanical fly ash recovery system, the fly ash discharges from ESP hoppers onto a series of mechanical conveyors that transfer the material to the load-out silo, as shown in Figure 2b. The silo in a mechanical recovery system requires explosion protection for the same reasons as a pneumatic system. Also, because the fly ash tends to become entrained in the air, the mechanical conveyors must be enclosed to contain the dust. This creates another enclosure capable of supporting a dust explosion and requiring protection.
Another explosion prevention method is to ensure that the LOI of the fly ash remains below the threshold at which the dust becomes explosive. This method is typically difficult to implement, however, because the composition of the fly ash continuously fluctuates.

Prevention and mitigation

Explosion protection methods for a fly ash recovery system fall into two general categories: prevention and mitigation. Prevention methods are designed to avoid an explosion by ensuring that at least one element of the dust explosion pentagon is absent from the system at all times.

The most common explosion prevention method is ignition source control, which includes belt monitors on conveyors, temperature sensors, magnets to detect rogue pieces of metal, and infrared detectors coupled with an extinguishing system.

Also, any additional dust collection equipment used to prevent nuisance fly ash from escaping either a pneumatic or mechanical recovery system may also require explosion protection.

Mitigation methods

A comprehensive explosion mitigation solution must protect all vessels in which an ignition source might start a dust explosion (including silos, filter receivers, dust collectors, and enclosed conveyors) by ensuring that the vessel’s interior pressure remains below the rupture strength during the explosion event. The mitigation solution must also prevent the explosion from spreading through any connected ducts or orifices to other process equipment or out into the workspace. The primary approaches to explosion mitigation are explosion venting, chemical suppression, and isolation.

Explosion venting. An explosion vent, as shown in Figure 3, relieves the pressure buildup in a vessel during an explosion to prevent the vessel from bursting or becoming damaged. In the event of an explosion, the vent opens or bursts at a predetermined pressure, allowing the dangerous pressure and flames to escape from the vessel and preventing the interior pressure...
from exceeding the vessel’s rupture strength. This allows the vessel to be reused after an explosion rather than needing to be replaced.

To operate safely, an explosion vent must exhaust to a safe location away from workers and nearby process equipment. If a vessel requiring protection is inside a production facility near walkways or other process equipment, for example, a standard explosion vent isn’t practical or safe. A flameless explosion vent, however, is designed to vent the pressure and flame generated by an explosion while maintaining a safe working environment around the vessel. A flameless vent, as shown in Figure 4, consists of a standard explosion vent panel with a robust stainless steel mesh cartridge mounted over the panel’s exterior. The mesh cartridge absorbs and contains the explosion’s heat and flames while dissipating the pressure generated to a safe level. Flameless vents are viable for protecting vessels handling fly ash because they require little maintenance and provide inherent safety for equipment located indoors.

**Chemical suppression.** If neither standard nor flameless venting are practical, chemical suppression is the next best option. A chemical suppression system, as shown in Figure 5, consists of a pressure sensor and one or more suppression bottles containing a suppressant material (typically sodium bicarbonate) and a propellant (typically high-pressure nitrogen). The pressure sensor detects a pressure increase in the vessel indicating an explosion and activates the suppression bottles, which inject suppressant into the vessel to actively extinguish the explosion before the pressure increase is great enough to rupture the vessel.

**Isolation.** When an explosion occurs inside a vessel, the pressure and flames generated will propagate down the path of least resistance, which is often through the vessel inlet and discharge. These openings must have a means of quickly shutting or otherwise preventing flames and pressure from escaping the vessel during an explosion event and spreading to interconnected equipment.

Vessel discharge openings are typically isolated using rotary airlock valves that have been tested and approved for explosion isolation. The rotating valve allows material to pass through the discharge during operation while preventing the passage of flames or pressure during an explosion.

A typical pneumatic fly ash recovery system outfitted with explosion mitigation devices is shown in Figure 6a, while a typical mechanical system is shown in Figure 6b. Remember that each application is different, so consult with a supplier to determine the best configuration of explosion mitigation devices for your fly ash recovery system.

**References**


2. All ASTM test protocols discussed in this article are available for purchase at www.astm.org.


**For further reading**

Find more information on combustible dust hazards and dust explosion prevention and mitigation in articles listed under “Explosion/fire protection” in *Powder and Bulk Engineering*’s comprehensive article index in the December 2016 issue or the Article Archive on PBE’s website, www.powderbulk.com. (All articles listed in the archive are available for free download to registered users.)

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