TESTING MATERIALS TO ACHIEVE OPTIMAL AIR FILTRATION

Almost every business in the powder and bulk solids industry uses dust collector and other particulate air pollution control equipment to ensure a safe and orderly workplace as well as comply with governmental regulations. No matter the material type used in your process, there’s no question that a filter will most likely be necessary. However, the material does matter when it comes to choosing the right type of separation equipment. This article describes the necessary material testing that should be performed when choosing a gas (or air)-material separator as well as how to use the test data to ensure the separator’s optimal performance.

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Whether you’re dealing with minerals, pharmaceuticals, dry dog food, or other powder and bulk materials, chances are likely that you’re going to need an air filtration or particulate air pollution control system. Two of the most common separator types are cyclones and baghouse filters, which include dust collectors and filter-receivers. There are many variations of each. Selecting this type of equipment, however, isn’t as straightforward as you might think.

There are various factors to consider depending on the type of separator you’re interested in, factors including the material’s terminal velocity, particle size, precise velocity calculations, and accurate material samples. You want the air-material separation process to be as efficient as possible to abide by federal regulations, reduce environmental pollution, achieve optimal production, and maintain a safe workspace. This efficiency can be achieved by testing your material’s properties in relation to the separators.

There are many types of particulate separators and filter media and also many types of material that need to be filtered. Your separator choices will require you to balance filter life and filtration efficiency against system cost. To optimize this tradeoff, be sure to take into account the different separator types, how each separator interacts with your material’s properties, and the precise calculations needed to make your process and separator operate as efficiently as possible.

Terminal velocity testing for gravity settling chambers

The most basic type of air-material separator is a gravity settling chamber, which works best for big, heavy particles such as clean pellets, grain, and rock. A gravity settling chamber, as shown in Figure 1, operates in the same manner as a silo, barge, or other large container. When large, dust-free particles are loaded or blown into the container, the solid material falls to the container’s bottom due to gravity while relatively clean air is vented out of the top. In a gravity settling chamber, the air-material stream enters the chamber through a small duct or pipe. As the air spreads across a larger cross-section of the chamber, the air velocity is reduced to the point where the solids drop out of the airstream. The point at which the air flowing upward carries the particles with it is called the material’s terminal velocity, and the enlarged chamber serves to reduce the air velocity to below terminal velocity, causing the particles to settle at the chamber’s bottom.

Terminal velocity is also used to describe the maximum velocity attained when something is dropped from a very high point. A skydiver, for example, accelerates and falls faster and faster until reaching a maximum terminal velocity due to air resistance. The skydiver will have greater air resistance and, thus, a
lower terminal velocity by holding a horizontal position while falling and will reach a higher terminal velocity by holding a vertical position. This same phenomenon applies to air filtration. In both cases, the solid object is pulled down by gravity through the airstream. The skydiver is falling downward through the air, whereas in the filter separator device, air is flowing upward past the particles being pulled down by gravity. In the filter separator, if the upward air velocity is below the particle’s terminal velocity, then the particle will fall to the bottom. But if the upward air velocity is greater than the particle’s terminal velocity, then the particle will be carried upward with the airflow. A material’s terminal velocity in the air depends on the individual particle’s density and shape. Much like the skydiver who becomes more aerodynamic in a vertical position, heavy and spherical or teardrop-shaped particles will have a higher terminal velocity and settle out of the air faster. In contrast, irregular and flake-shaped particles aren’t aerodynamic, have a low terminal velocity, and are more likely to float and stay in the airstream rather than be separated from it. Although there are other ways to measure a material’s terminal velocity, the most common and simplest way is with a vertical velocity testing device. A sample of material is placed on a porous surface within a clear, vertical tube, as shown in Figure 2. From beneath the porous surface, air or another gas is directed upward at a controlled velocity. The material is observed as it interacts with the air moving through the porous surface, and when the material is lifted via the airstream, the air velocity measured at this point is the material’s terminal velocity.

To efficiently use a gravity settling chamber, an operator should measure the material’s terminal velocity and then design the system to ensure upward air velocity remains below that point.

**Particle size testing for cyclones**

Simple gravity settling chambers alone rarely work well for anything but materials with big, heavy particles. Therefore, a cyclone is often used in some applications that have a variety of particle sizes. A cyclone relies on sidewall friction to slow the material and enhance particle separation from the air. Gravity also plays a part in a cyclone’s separation efficiency as gravity pulls the particles to the cyclone’s bottom as they are spun against the sidewall. Centrifugal force and particle momentum in the cyclone’s outer vortex cause the solid particles to be thrown against and slide along the cyclone’s internal wall, as shown in Figure 3. Gravity plays a part by pulling the air and particles downward in a spiral, which continues until it reaches a point near the bottom where the particles slow greatly due to friction and are discharged. At this point, the clean air continues spiraling but reverses direction due to the cyclone’s internal geometry, spiraling upward via the inner vortex until the air is drawn out through the cyclone’s center. This combination of spinning, friction, and gravitational force is the principle upon which a cyclone separator works.
The optimal geometry of a high-efficiency cyclone was determined in the mid-twentieth century, and the results are still valid. High-efficiency cyclone geometries should always be used because they impart the correct air-material velocity within the cyclone to achieve best results. If something changes, such as a too-high or too-low airflow velocity or the sidewall is not long enough to impart adequate wall friction, then separation efficiency will suffer. Low-efficiency cyclone designs might be shorter and less expensive to build, but their lower efficiency will usually not comply with workplace or clean air regulations. Furthermore, proper design of the cyclone's inlet, outlet, and transition section is critical. Smooth transitions that avoid turbulence are required to establish an uninterrupted vortex. Since the airflow speed is above the material's terminal velocity, any turbulence can cause particles to become re-entrained and carried away by the airstream instead of remaining separated from it.

Cyclone separation efficiencies can be very good, especially for medium and larger particles above 20 microns in size, as shown in Figure 4. The cyclone efficiency graph shows that separation efficiency is a function of particle size. Particle size distribution can be determined by providing a material sample to a particle testing lab. If the material contains a variety of particle sizes, as is typically the case, then the overall cyclone efficiency can be calculated by determining the cyclone's separation efficiency for each particle size present in the mixture. Then you can calculate a weighted average of the cyclone's efficiency for your material based on the proportion of material in each particle size range. The graph will accurately predict separation efficiency as long as the cyclone operates continuously.

Cyclones work well for materials that are made up of medium and large particle sizes. In addition, cyclones are often the best separator choice for sticky or tacky material that would clog other filter types, such as bin vents and filter-receivers. These fabric filter-based separators are preferred for many other types of materials however.

**Terminal velocity and particle size testing for filter-style collectors**

Most industrial applications require an even more precise particulate air filter than a settling chamber or cyclone, which work well enough when handling medium to large particles. When it comes to very small particles, such as silica and talc, a dust collector is a good investment in order to separate the solids from the air. A dust collector uses a cloth bag or cartridges as a filter media. Material particles collect on the filter element's exterior while clean air passes through the element’s center and exits out the top. Compressed-air pulses clean a single row of filter elements at a time while the other filter element rows remain in filtering mode, as shown in Figure 5.

Two common dust collector styles are called bin vents and filter-receivers. A bin vent, like the one shown in Figure 6, sits on top of either a bin or silo and is used to filter the dust from the air as material falls into a vessel. Since the air is typically vented to the atmosphere, a bin vent can be square or any shape as it doesn’t need to withstand appreciable vacuum or pressure. In comparison, a filter-receiver is used at the destination end of a pneumatic conveying system and has a cylindrical shape, as shown in Figure 7, since the filter-receiver needs to withstand vacuum or pressure.
A dust collector unit relies on several mechanisms to separate particles from the airstream. Most of these units are designed so that the air-material stream enters the unit below the filters. This allows gravity to do much of the work, as a majority of particles will settle out of the air and won’t reach the filters. Terminal velocity testing, as described earlier, is the most important consideration for this method of separation. In addition to gravity, a round filter-receiver with tangential inlets can separate the material from the air using cyclonic action in which particle friction against the sidewall helps slow the particles so their speed falls below terminal velocity and they aren’t carried up into the filter with the air.

After separation via gravity, all of the air and some of the particles move up into the filter section where the dust collector uses several more mechanisms to capture the remaining particles. When a filter begins operating, particles build up on the outside of each filter element, which becomes the “dirty” side of the filter. As particles enter the filter unit, they form a cake on the outer filter surface, which is why this layer is appropriately named filter cake. This filter cake catches even more particles, growing thicker over time, and provides some of the most important filtration. A variety of small and large particles actually helps achieve a proper and porous filter cake. And while combining separator devices can be beneficial to some processes, placing a cyclone in front of a dust collector is generally not recommended because a combination of small and large particles in the airstream improves a dust collector’s performance. Placing a cyclone in front of a dust collector would result in the cyclone removing the larger particles, leaving only fine particles for the dust collector. The result of that is undesirable because a filter cake made of only fine particles is denser and has more resistance than a filter cake made with a variety of particle sizes. For the particles not caught in the outer filter cake, another level of filtration occurs in the filter fabric, in which the smallest particles follow the tortuous path of air through the fabric but are caught when they touch the filter’s fibers. Thus, particle size and particle size distribution are the most important parameters to be tested for these separation mechanisms.

Another important consideration is called can velocity. Below the filter section, the air and particles flow upward at a relatively slow velocity. Once the air and remaining solids reach the bottom of the bag or cartridge filter, all of the air is squeezed into the much smaller interstitial area between the filters. This critical location is the point at which the highest upward velocity, also called can velocity, occurs. Above this point, velocity diminishes because the air exits the dirty portion of the filter unit (the filter element’s exterior) and starts flowing through the clean portion.

Material is supposed to be filtered on the filter element’s exterior, then fall off and drop to the bottom when the filters are pulsed clean. However, if the can velocity at the filter element’s bottom is too high, the upward air velocity will keep the material from dropping. Particles will then quickly re-entrain on the filters instead of falling to the bottom, and the filters may quickly blind over or become clogged with too much material. Blinding occurs when the spaces between the filter’s fibers get clogged with bits of material. This builds up over time and eventually clogs the fabric completely so that solids and air can’t pass through. Accordingly, testing your material’s terminal velocity is
critical for proper dust collector design to prevent can velocity from leading to a potential failure mode.

**Your material’s properties and filter media selection**

There are many types of filter media, and your choice will have a large impact on the cost and performance of your dust collector. In addition to application aspects such as air volume and temperature, material properties can have a large effect on a filter’s performance and the life of the filter elements.

First, you must determine whether your dust collector will use bag or cartridge filters. Bag filters or socks are the least expensive, but cartridge filters offer better filtration efficiency and can reduce the dust collector size. When making a filter media decision, however, it’s important to note that certain material characteristics may dictate the answer. Pleated cartridge filters squeeze more filter area into a given volume, but some material shapes will get caught in the pleats and pulse-cleaning won’t dislodge them. This most often occurs when the particle shape is flat, flakey, or jagged, so bag filters are the better choice in this scenario.

Other material properties, such as adhesiveness and cohesiveness, can cause further filtration problems. These sticky materials may adhere to the filter element. This is especially true for standard bag filters made with felted fibers; materials can stick to them and cause blinding and premature failure. You may need to use a filter element with a polytetrafluoroethylene (PTFE) surface membrane to prevent the material from sticking. Alternatively, if your material contains oil, then the material is sure to blind the filter, and an oleophobic filter media (one that repels oil) should be considered.

Still, other material properties can cause potential hazards that must be addressed. If a dust explosion is possible with your material, then the dust collector and filter elements must be designed with this in mind. Several methods for preventing and, at the very least, minimizing the effects of potential explosions are available. Many explosion protection methods are quite expensive but may be required for safety reasons and to comply with OSHA regulations and NFPA standards. You’ll want to determine if these explosion protection measures are even necessary for your material. If so, you’ll need to determine your material’s explosibility factors, such as minimum ignition energy and maximum pressure generated, which can only be established through testing. Once determined, these values can be readily used by the filter supplier or system designer to choose the proper safeguards for the filter media, filter unit, and ducting.

**Other tips and considerations**

**Material samples.** When obtaining a material sample for evaluation, your test sample should be taken using the proper methods to get a representative sample. For example, the top of the sample pile will probably have less dust than the bottom, and the sample will need to be made up of material from both locations. The sample should represent actual material that will be filtered. In addition, if your material is friable, then the material as it enters the dust collector may have smaller particle sizes than the material as it entered the feedpoint or as received from the supplier. This is especially true with a high-velocity pneumatic conveying system. Make sure your sample represents the material being handled at the subject separator.

**Calculations.** When calculating airflow and velocity, be sure to base the figures on conditions at the separator. Due to gas (air) compressibility, the air volume and velocity can be much different at the air filtration system’s end than at the beginning. In other words, don’t forget to include the effects of pressure or vacuum, temperature, and altitude in your air volume calculations. Air velocity in any separation device is important, so take care to ensure a uniform distribution of air as it enters and exits the unit. Turbulence and areas of high or low velocity will cause particle re-entrainment and can be avoided with the proper design of transitions, adjacent ducting, and elbows.

**For further reading**

Find more information on this topic in articles listed under “Dust collection and dust control” and “Particle/Powder analysis” in Powder and Bulk Engineering’s comprehensive article index in the December 2019 issue or the article archive on PBE’s website, www.powderbulk.com.

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