A pneumatic conveying system uses a moving gas stream (typically air) to transport bulk solid materials from one point to another through a pipe or tube called a conveying line. In dilute-phase pneumatic conveying, the solids concentration is low relative to the gas concentration and particle-to-particle interaction is limited. In dense-phase pneumatic conveying, the solids concentration is high relative to the gas concentration and particle-to-particle interactions are high. In this column, I’ll focus on dilute-phase pneumatic conveying. I’ll cover dense-phase pneumatic conveying in a future column.

Dilute-phase pneumatic conveying has been around since the invention of the Duckham pneumatic elevator in the late 1800s. Early dilute-phase pneumatic systems were used mainly for loading and unloading ships carrying grains and gunpowder. Today, dilute-phase systems convey powders, granular materials, ingots, balls, manufactured parts, and even live chickens. Systems range from very small scale, with conveying rates measured in grams per minute, up to very large scale, with conveying rates approaching 600 t/h. Conveying distances can range from a few feet up to 8,000 feet (approximately 1.5 miles).

Dilute-phase pneumatic conveying is often the most cost-effective and reliable means of bulk solids transport. Systems typically have a lower initial capital cost than mechanical conveying systems and are totally enclosed, which limits dust exposure and material contamination. Pneumatic systems are also easier to automate than mechanical systems. However, dilute-phase pneumatic conveying systems can have higher operating costs due to the higher horsepower requirements for the system’s blower. Pneumatic systems can also be problematic because many plant workers lack a basic understanding of pneumatic conveying concepts.

In this column I’ll explain the basic components and operating principles of a dilute-phase pneumatic conveying system. I’ll also discuss parameters to consider when designing a dilute-phase pneumatic conveying system as well as a few common drawbacks of dilute-phase conveying.

Pneumatic conveying system components

The basic components of a typical dilute-phase pneumatic conveying system, as shown in Figure 1, are a conveying line, a gas mover, a feeder, and sometimes a gas-solids separator (not shown).

Conveying line. The conveying line is the tube or pipe through which the material is conveyed and can be stainless steel, carbon steel, aluminum, plastic, or rubber, depending on the application’s structural and erosion resistance requirements. Dilute-phase conveying line is commonly made from light-gauge pipe (such as Schedule 10 metal pipe) unless the system will be conveying at high pressures and require a heavier-gauge pipe.

The line can be configured with any combination of horizontal, bend, splitter, riser, and downer components but typically consists of primarily horizontal and riser sections. When designing a system, you should try to limit the number of bends in your conveying line because bends significantly increase the system’s pressure drop (a measure of the system’s internal friction, or resistance to flow), which limits the system’s conveying capacity. Bends are also a source of particle attrition and conveying line erosion (discussed later in this column). To minimize these affects, system designers often use techniques such as having two 45-degree bends separated by a straight section instead of using a single 90-degree bend.

Gas mover. A pneumatic conveying system gas mover drives the conveying gas that carries the material. As previously stated, the conveying gas is typically air, but some systems use an inert gas (such as nitrogen) to convey highly explosive materials. Gas mover types include fans, blowers, compressors, and vacuum pumps.
A fan uses a rotating impeller to build pressure and drive the conveying gas and comes in two types: axial and centrifugal. An axial fan moves gas in one direction, parallel to the impeller’s axis, while a centrifugal fan moves gas radially, meaning that the direction of the outward-flowing gas is different (usually by 90 degrees) from the direction of the incoming gas. Most fans used in pneumatic conveying are centrifugal fans because they deliver a steadier gas flow than axial fans. 4

Fans are the least expensive gas mover type and typically have lower maintenance costs than the other types, but fans are limited in pneumatic conveying applications because the pressure generated is highly dependent on the load. An increasing material load eventually overcomes a fan’s ability to generate pressure and move the material, so the fan must be sized to operate in the region of the fan curve that presents the most stability with varying material loads.

A blower (also called a rotary lobe or Roots blower) has two rotors, each with either two or three intermeshing lobes that capture and drive the conveying gas into the conveying line as they counter rotate. A blower is considered a positive displacement device because, unlike a fan, a blower forces a fixed amount of gas into the conveying line with each rotation regardless of the pressure or material load in the line. Blowers typically achieve compression ratios ranging between 1.1 and 2 (outlet pressure to inlet pressure) and provide a more constant gas flowrate than fans at varying discharge pressure. However, blowers tend to be more expensive and less reliable than simple, centrifugal fans, and at low rpm, gas pulsing can be an issue with blowers (although this is less of a problem with three-lobe blower designs).

A compressor is a positive displacement device in which reciprocating vanes or screws compress the conveying gas, usually to 2.5-or-higher compression ratios. While compressors are good at generating pressure, they can become cost prohibitive for systems with high gas-flow requirements, so they’re only used in high-pressure pneumatic conveying applications.

Fans, blowers, and compressors all “push” the conveying gas through the conveying line from the beginning of the system. This is called a positive pressure or push configuration. You can also configure the system to “pull” the conveying gas through the conveying line by using a vacuum pump at the end of the system. This is called a negative pressure, vacuum, or pull configuration. Pneumatic conveying systems conveying material from multiple sources to a single destination, as shown in Figure 2a, typically use vacuum pumps. For a system conveying material to multiple destinations, as shown in Figure 2b, a vacuum pump should not be used and a fan or blower should be considered instead.

Gas mover size is determined by calculating the pressure drop (using widely available equations5) for each system component downstream from the feeder. Calculations must include all conveying-line sections and the gas-solids separator (if applicable), under material loading at the required gas flowrate. For example, the pressure drop calculations for the system in Figure 1 must include both the frictional loss at the conveying line wall and the particle acceleration and reacceleration in the first horizontal section, first bend, riser section, second bend, second horizontal section, and cyclone. For the systems in Figure 2, the calculations will be similar, but because the systems include multiple material pathways, the system pressure drop must be calculated based on the configuration that provides the highest pressure drop, which is usually the longest path length.

**Feeder.** Common feeders for dilute-phase conveying lines include rotary valves, slide valves, screw feeders, double flapgate valves, venturis, and wands.

The rotary valve, as shown in Figure 3a, is the most common dilute-phase feeder and consists of a rotor (typically with 6 or 8 blades or vanes), housing, head plates, packing seals, and bearings. Rotary valves can be driven by either fixed or variable-speed drives depending on the application. New rotary valves typically have a clearance of just a couple thousandths of an inch between the rotor vanes and the valve housing and provide a good seal between the conveying line and the feed source while allowing good volumetric material flow into the conveying system — as long as the material is free-flowing. The rotating vane tips can wear quickly, however, and cause
chamber in between. The valves open and shut in sequence to allow material to flow into the conveying system but prevent conveying gas from escaping past the feeder. Like the rotary valve, the double flapgate valve provides a good seal between the conveying line and the feed source. Double flapgate valves are primarily used for feeding chunky or fibrous materials that could jam or damage a rotary valve feeder.

The venturi (or eductor) feeder, as shown in Figure 3e, provides a non-mechanical solution for feeding material into a pneumatic conveying system. The venturi uses a narrow gas flow section followed by a wider section to generate an upstream vacuum and suck material into the conveying line. A venturi has no moving parts and can provide conveying rates of more than 20,000 pounds per hour but has limited feedrate control and tends to be used as more of an off-or-on device than an adjustable feeder. As with the screw feeder, having a shut-off valve such as a slide valve in place is a good idea to fully stop the material flow.

A wand, as shown in Figure 3f, is typically used with a vacuum system and is an extension of the conveying line with an open end, much like the vacuum hose on a household vacuum cleaner. Wands can be stationary and mounted inside a hopper or connected to flexible hose for manual material uptake from a truck or rail car. Wands typically work well for free-flowing materials but can be problematic and plug with sticky material.

**Gas-solids separator.** Dilute-phase conveying systems often require that airborne material be separated from the conveying gas once the material has reached its destination. This is done with either a filter-based dust collector or a cyclone. Filter-based units use perforated-screen, ceramic, cloth, or paper filters to separate fine particles (down to about 1 micron) from the gas stream. Additional fines collection can be done downstream from the dust collector if needed.

A cyclone separator, as shown in Figure 4, is mechanically simpler than a filter-based dust collector and costs less to operate and maintain. A cyclone separator can also offer a lower and more...
consistent pressure drop. However, a cyclone separator doesn’t separate fine particles as efficiently as a filter-based separator, and systems will often include a filter-based unit downstream from a cyclone to further clean the conveying gas.

Some dilute-phase conveying systems have no separator in place, and such systems can reduce capital and operating costs. However, you should also consider environmental conditions and dust exposure to workers and downstream equipment.

**Particle flow in pneumatic conveying lines**

As shown in Figure 5, particle flow in a typical horizontal conveying line can be divided into regimes based on the gas flowrate. A typical dilute-phase pneumatic conveying system should be designed to produce homogeneous flow, which occurs at high gas velocities, where the material is fully entrained in the gas stream. If the gas velocity decreases, some particles may remain entrained in the gas stream while others begin to drop out and slide along the bottom of the conveying line. This is called saltation flow. If the gas flowrate continues to fall (as a result of higher material loading in a system with a fan, for example), all the material will drop out of the gas stream and tumble along the bottom of the conveying line. This is called dune flow. Dune flow can cause many problems in a pneumatic conveying system, the biggest of which is that material remains in the conveying line after the system is shut down. This can contaminate the next material, lot, or batch conveyed in the system. As the gas velocity continues to decrease, more material fills the conveying line, resulting in slug or ripple flow (not shown), which are associated with dense-phase conveying.

To ensure that your system produces homogeneous flow, you must know your material’s saltation velocity. Saltation velocity is the gas velocity at which particles begin to drop out of the gas stream in a horizontal conveying line section. A material’s saltation velocity can be calculated, but testing provides the most accurate determination of a material’s saltation velocity.

Operating your conveying system below the saltation velocity results in the onset of dune flow, so your gas velocity should be slightly higher than the saltation velocity. The velocity must be high enough that system perturbations don’t cause the gas velocity to drop below the saltation velocity but low enough to prevent unnecessary energy use, conveying-line erosion, and particle attrition.

The graph in Figure 5 shows a typical pneumatic conveying capacity profile for dense- and dilute-phase conveying. The graph plots the material flowrate (conveying capacity) versus the gas flowrate at three different pressure-drop (ΔP) levels in a conveying line. For a fixed gas flowrate, a higher pressure drop corresponds to a higher conveying capacity in the line. However, with dilute-phase conveying, higher gas flow doesn’t result in higher conveying capacity. Actually, the opposite is true; increasing the gas flow reduces the conveying capacity for the same overall pressure drop.

If material contamination between batches is an issue, a system’s minimum gas velocity may need to be based on the material’s pickup velocity rather than its saltation velocity. Pickup velocity is the minimum gas velocity required to “pick up” particles at rest and re-entrain them back into the gas flow. The problem with using pickup velocity is that it must be determined experimentally as no testing standard exists yet. Also, the pickup velocity in the test unit needs to be based on the local gas velocity, not the superficial gas velocity. The superficial gas velocity for picking up a small amount of material in a conveying line will be different from the superficial gas velocity for picking up a large amount of material piled in dunes because the local gas velocities will be different. So, which pickup velocity should you test for? The answer unfortunately is “it depends.”

**Basic design concepts**

A dilute-phase pneumatic conveying system’s effectiveness depends on many design parameters. Some parameters, such as the material’s salutation and pickup velocities, should be determined by testing the material in a lab. For less well-characterized materials, even the pressure drop in straight conveying-line sections and bends should be tested. Fortunately, many pneumatic conveying system suppliers have test units available.

To estimate the configuration and cost of a new dilute-phase conveying system, work with your supplier to follow these steps:

1. Determine whether your application requires a positive or negative pressure system
2. Develop a preliminary layout
3. Estimate the pipe or tube size
use specialized bends such as blind tees that trap material at the impact region so particles collide with other particles instead of the conveying-line wall, reducing particle attrition. Adding specialized bends to an existing system may increase your system’s pressure drop and compromise performance, however, and if the pressure drop is too high, you may need to consider using a dense-phase pneumatic conveying system instead.

Diverter valves. Conveying systems with multiple sources or destinations use diverter valves to direct material flow (Figure 2). Such valves add flexibility to your operation but have limitations if used as flow splitters. Particle concentration in a pneumatic conveying line may not be radially uniform, so if that material stream is split, the overall particle flow may not be split evenly between the branches, even if each branch is operating in homogeneous flow. This can lead to non-uniform or segregated material flow.

Dilute-phase pneumatic conveying drawbacks

While dilute-phase pneumatic conveying can be a reliable, cost-effective conveying method for a range of applications, it does have some drawbacks.

Particle attrition. The high gas velocities used in dilute-phase systems can lead to high particle attrition at conveying-line bends. If you’re conveying polymers, for example, this can lead to floss and fines which degrade product quality. If particle attrition is a concern for your material, you can use specialized bends such as blind tees that trap material at the impact region so particles collide with other particles instead of the conveying-line wall, reducing particle attrition. Adding specialized bends to an existing system may increase your system’s pressure drop and compromise performance, however, and if the pressure drop is too high, you may need to consider using a dense-phase pneumatic conveying system instead.

Conveying-line length. For a long conveying line, the pressure drop can be substantial. Along with needing the correct gas mover size, you may also need to be concerned about the gas velocity at the end of the line. With each foot along the conveying line, the gas pressure decreases and the velocity increases. In a long conveying system, gas velocity may become too high, causing excessive particle attrition and erosion, which can be a costly issue. If this is a problem in your system, you may need to bleed off some of the gas or increase the conveying-line diameter, which will also allow you to better manage particle attrition and erosion in bends. Temperature changes over the conveying-line length can also significantly impact gas and particle velocity.

Irregular particles. Most calculations used for designing pneumatic conveying systems are based on hard, spherical particles. Soft or elastic particles can result in pressure drops up to three times higher than calculated. High-speed video has shown that elastic pellets lose most of their momentum when colliding with or even glancing against the conveying-line wall. As a result, the particles need to reaccelerate, which can significantly increase the system’s pressure drop. Non-spherical particles add a similar degree of complexity and are more prone to plugging as well, especially if the conveying line is

4. Calculate your material’s saltation velocity
5. Estimate the pressure drop in the horizontal sections, risers, bends, and separators (if applicable)
6. Calculate the fan or blower size
7. Select the fan or blower required for stable performance using a fan performance curve
8. If the fan performance curve shows that the fan or blower you selected doesn’t meet your system’s criteria, alter the system layout or change the fan or blower.

Complex configurations. A dilute-phase pneumatic conveying system won’t perform well if the conveying line configuration is too complex. Make sure bends, diverters, splitters, and other devices that affect flow aren’t too close to each other or the asymmetric flow conditions imposed by the upstream device will affect the performance of the downstream device. A good rule of thumb is to allow a straight-section conveying length of 15 to 20 times the diameter of the pipe before adding a bend, diverter, splitter, or any device that would perturb the flow. This allows the material to regain full conveying velocity between perturbations.
poorly constructed, with gaps or protrusions where material can snag and accumulate.

References


For further reading

Find more information on this topic in articles listed under “Pneumatic conveying” in *Powder and Bulk Engineering*’s article index in the December 2016 issue and in the Article Archive on *PBE*’s website. (All articles in the archive are available for free download to registered users.)

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