Particle degradation is a major concern when pneumatically conveying a fragile material. This article briefly discusses some advantages of pneumatic conveying systems over mechanical conveying systems and the types and costs of particle degradation. The article also explains the different pneumatic conveying phases and how to optimize a pneumatic conveying system to gently convey a fragile material.

Companies have traditionally used mechanical conveying systems, such as belt, screw, or bucket conveyors, to convey fragile materials because these systems can handle such materials gently, without causing particle degradation. However, a pneumatic conveying system can be configured to handle material just as gently without the dust, spillage, cross-contamination, and high maintenance costs often associated with a mechanical conveying system.

A typical pneumatic conveying system, as shown in Figure 1, consists of a feed bin, a feed valve, a gas mover (not shown), a conveying line, a reception bin, and a bin vent or dust collector. Many systems also have a pressure vessel (Figure 1) below the feed valve to maintain the pressure differential between the feed bin and conveying line. In operation, the feed valve opens, allowing material to flow from the feed bin into the pressure vessel (if applicable). Conveying gas from the gas mover then forces the material through the conveying line and into the reception bin. The conveying gas is then typically exhausted through the bin vent, which separates any remaining fines from the gas stream.

Since a pneumatic conveying system is totally enclosed, there’s virtually no dust or material spillage, but completely sealing a mechanical conveyor is difficult, especially at material transfer points. Dust can escape and migrate throughout the plant, creating an explosion or fire hazard. Material can also spill into operating areas causing rodent, insect, and bacteriological problems in some applications.

**Figure 1**

Typical pneumatic conveying system

- Conveying line
- Feed bin
- Feed valve
- Pressure vessel
- Reception bin
- Bin vent
Cross-contamination between different ingredients or batches can also be a serious problem with mechanical conveyors, particularly in the food and animal feed industries. A pneumatic conveying system can be easily purged of material using high-velocity air, either between ingredients or at the end of a batch run, to prevent cross-contamination. Cleaning a mechanical conveying system is more difficult and usually involves disassembling the equipment and hand-cleaning individual components.

Since a pneumatic conveying system has few moving parts, it requires little maintenance to perform reliably, while a typical mechanical conveyor has many moving parts, which wear and break down as the system ages, leading to costly downtime and repairs.

However, not all pneumatic conveying systems are suitable for handling fragile materials, particularly in applications where particle degradation is a concern. Before discussing how to successfully pneumatically convey a fragile material, let’s look at what particle degradation is and how it can affect your operation.

**Particle degradation in a pneumatic conveying system**

Particle degradation occurs when the individual particles of a bulk solid material fracture, abrade, rupture, or are otherwise damaged during handling. In a pneumatic conveying system, this is typically caused by high-velocity impacts or friction between particles or between particles and system walls. For some materials, such as coated food pellets and dry pet food, the particle itself may not degrade, but its coating may be damaged or separated from the particle. For other materials, such as sesame seeds, raisins, and peanuts, the particle may not actually break apart, but impact or abrasion damages its cells or structure. For example, oil cells in a peanut’s surface layers can rupture and release oil.

Particle degradation, whatever its cause, can cost you money. Often, you must separate the degraded particles and fines from the material stream and either recycle or dispose of them. This adds an additional processing step and its accompanying costs to your operation. Also, if you’re damaging or losing a percentage of your material during conveying, you’ll need to account for that loss by increasing the amount of material you process. In some instances, the damaged material isn’t a total loss, but its value is reduced. Fish-food pellets for the fish-farming industry, for example, contain oils or coatings with essential nutrients and vitamins. Losing or degrading these ingredients during conveying greatly reduces the pellets’ nutritional value for the fish and, consequently, the pellets’ financial value.

Fines or oils created by particle degradation can also build up within your conveying system or in downstream process equipment, reducing the equipment’s efficiency and requiring more frequent cleaning and maintenance. Very fine particles can also escape into open areas and settle on plant surfaces, requiring frequent cleanup.

**How material characteristics affect pneumatic conveying**

To avoid particle degradation in your pneumatic conveying system, you must understand your material’s characteristics. A material’s friability, or degree of fragility, largely determines the velocity at which it can be pneumatically conveyed without sustaining excessive particle degradation. Some materials, such as silica sand, are quite hard and can be successfully conveyed at higher velocities than other, more delicate materials, such as peanuts, popping corn, or sesame seeds.

Material characteristics can also be used to predict if a material can be easily fluidized, which will help to determine which pneumatic conveying phase (discussed later in this article) will best convey the material. Fluidization occurs when a material’s particles become entrained in the conveying gas, reducing interparticle friction and causing the gas-solid mixture to have liquid flow characteristics. A material’s particle size distribution is used to calculate the material’s average particle size, which, along with particle shape and material bulk density, influences how readily the material will fluidize. A material with relatively spherical particles, such as fly ash and cement, will tend to fluidize more easily than a material with irregularly shaped particles, such as silica sand or granular sugar, which tend to lock together and resist fluidization.

**Pneumatic conveying phases**

A pneumatic conveying system can convey material in four main phases: dilute phase, continuous dense phase, discontinuous dense phase, and solid dense phase. The conveying phase is largely a function of the conveying velocity.

**Dilute phase.** Dilute-phase pneumatic conveying uses high-velocity conveying gas to move the material in a suspended flow pattern, as shown in Figure 2a. The conveying velocity can vary between 12 and 18 m/s at the system’s feed end and between 20 and 30 m/s at the system’s endpoint. Particle degradation increases substantially at higher velocities. In dilute-phase pneumatic conveying, particle degradation is caused by particles impacting conveying-line walls, deflectors, and other particles.

**Continuous dense phase.** Continuous dense-phase conveying uses a moving-bed flow pattern, as shown in Figure 2b, in which much of the material slides along the
Conveying-line bottom, and only some of the material is suspended in the conveying gas. This provides a lower conveying velocity than a dilute-phase system, ranging between 5 and 10 m/s. Far less material is suspended in the conveying gas, reducing particle degradation, which is mainly caused by medium-velocity impacts and abrasions as the material slides along the conveying line. Continuous dense-phase conveying typically only works best for fluidizable materials with relatively high air-retention properties, such as fly ash and cement.

Discontinuous dense phase. Discontinuous dense-phase conveying is characterized by a plug flow pattern, as shown in Figure 2c. This phase works well for most fragile materials because the average conveying velocity is low — in the 1.0- to 5.0-m/s range — and because of how the material flows in the conveying line. In plug flow, material fills the conveying line’s entire cross section, with plug lengths ranging from 0.5 to 10 meters depending on the application, so much less material is exposed to contact with the conveying-line walls. This greatly reduces particle degradation from abrasion. Also, the low conveying velocity substantially reduces impact damage and virtually eliminates impacts between suspended particles. Materials such as sugar, salt, petroleum coke, and sand convey well in discontinuous dense phase.

Solid dense phase. In solid dense-phase conveying, material completely fills the conveying line and moves in an extrusion flow pattern, as shown in Figure 2d. The conveying velocity is very low, usually in the range of 0.25 to 1.0 m/s. The very low conveying velocity is particularly suited to oil-impregnated materials, where it’s important that the oils aren’t separated from the particles. Solid dense-phase conveying can typically only be used for materials that are too fragile for other conveying phases and that have round, relatively large particles and relatively small particle size distributions, such as peanuts, popping corn, and sesame seeds.

To convey a fragile material, you should select the phase that provides the lowest conveying velocity and most stable conveying-line conditions, while also considering factors such as your required conveying rate and the system’s size. A very low conveying velocity might be gentler on your material, for example, but might require a larger system to meet your application’s conveying-rate requirements, adding to the system’s cost. Conveying at a slightly higher velocity in a smaller system might allow you to reduce the system’s cost and still meet your particle degradation requirements.

Optimizing your pneumatic conveying system to avoid particle degradation

To optimize your pneumatic conveying system to gently handle a fragile material regardless of the conveying phase:

- Avoid a system that relies on fluidizing the material or pressurizing the feed bin prior to opening the feed valve. This usually results in a high discharge velocity, which can cause particle degradation.
- Use a mass-flow feed bin and, if possible, avoid using vibration or aeration devices to aid material discharge. Any turbulence created by these devices can cause particle degradation.
- Use a full-ported feed valve, such as a ball valve or inflatable-seal valve to encourage mass flow from the feed bin and eliminate particle degradation caused by material impacting valve components. With a butterfly valve, for example, particles can be damaged by the disk and shaft, which remain in the valve port when the valve is open. Also, avoid using a slide gate, which is difficult to pressure seal and may crush material when closing.
- If your system uses a pressure vessel, use the smallest one your application will allow to shorten the material’s fall from the feed bin into the vessel. This will help to minimize particle degradation as the pressure vessel is filled.
• Avoid a “booster” system that injects additional conveying gas directly into the conveying line to prevent plugs from becoming too dense and blocking the line. This usually increases the conveying velocity and causes turbulence at each injection point, increasing particle degradation. Some pneumatic conveying systems use an internal or external gas bypass system instead of boosters. This typically doesn’t increase conveying velocity or cause particle degradation because, rather than adding gas to the system, a bypass allows the existing conveying gas to bypass the material from the rear of the plug to the front.

• Keep your conveying-line configuration as simple as possible to reduce particle degradation from impacts. Try to include no more than one vertical section, and arrange for it to occur as close to the system’s start as possible. Also, avoid using inclined conveying-line sections greater than 15 degrees from horizontal. Multiple vertical sections and steep inclines up to about 70 degrees can cause material backflow, where some material falls or slides backward in the conveying line. At best, this causes a double-handling effect and can increase particle degradation. At worst, it can cause dense slugs to develop and raise the system pressure, which can negatively affect conveying stability and velocity.

• Ensure that all conveying-line connections are properly aligned. Even at low velocity, particle degradation can occur as particles impact the exposed ledges of poorly aligned conveying-line sections. Choose flanged joints — ideally with male and female flanges, as shown in Figure 3a — rather than welded connections, as shown in Figure 3b, or couplings, as shown in Figure 3c.

• If possible, keep the system’s reception bins topped up with material, as shown in Figure 4a, to reduce the distance the material has to fall when discharging from the conveying line. The material pile in the bin will also tend to “cushion” the discharged material’s fall compared to the bin’s metal bottom. Use a high-level probe to maximize the bin’s material level but prevent overfilling (Figure 4a). For a large bin that must be regularly emptied for batch-control purposes, use an internal spiral letdown chute, as shown in Figure 4b, which allows the material to gently slide to the bottom of the empty bin. Also, avoid a configuration in which the material entering the reception bin impacts the bin’s walls rather than the material pile.

Testing your material
The best way to ensure that a pneumatic conveying system can convey your material without particle degradation is to have one or more conveying system suppliers test a sample of your material. The test program should demonstrate the gas flows and pressures, the cycle time and system capacity, whether the conditions in the conveying line are smooth and stable, and the particle size distribution before and after several test runs, using fresh material each time. The supplier can use the particle size distribution to calculate your material’s average particle size before and after each run and determine how much degradation occurred, but you may also have your own proprietary test to determine the actual particle degradation caused by the tests.

The tests should be full scale, using production-sized equipment and relevant conveying distances, and the test results should include practical recommendations for optimizing the recommended conveying system.

References
Figure 4

Reception-bin configurations

a. Bin with topped-up material

Material level topped up

High-level probe

b. Bin with spiral letdown chute

Spiral letdown chute

Empty bin

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 2014 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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