Dense-phase pneumatic conveying: Applications, system design, and troubleshooting

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The use of dense-phase pneumatic conveying is growing in bulk solids plants because the method’s low velocity provides gentler handling for some materials and causes less conveying line wear than dilute-phase conveying. After describing applications for the method, this article explains how to decide if dense-phase conveying is right for your application, how to avoid some common problems when designing your own dense-phase conveying installation, and how to troubleshoot the system.

Dense-phase pneumatic conveying has traditionally been applied to transporting only a few abrasive materials like cement and fly ash. But in the last 10 years, global suppliers of foods, chemicals, pharmaceuticals, building materials, minerals, and other products have been installing low-velocity dense-phase conveying systems at a rapid rate. Why? These producers handle millions of tons annually. They know that at these high production rates, the dense-phase system’s gentler handling can provide enormous cost savings by reducing material breakage and conveying line wear — even if only by a fraction of a percent — over that in a dilute-phase system.

Some pneumatic conveying basics
To understand how dense-phase conveying provides advantages over dilute-phase conveying, it’s helpful to look at some pneumatic conveying principles.

Velocity in dense- and dilute-phase conveying. In any type of pneumatic conveying, the flow of conveying air (or gas) accelerates material in a conveying line to a design velocity, and the material contacts the conveying line walls, changes direction in the line elbows, and falls back to the material’s original resting state at the system’s destination (typically a vessel such as a hopper).

Some materials hold up better than others during this process, but in all cases, the percentage of material breakage is proportional to the average material velocity in the conveying line. In a dense-phase conveying system, the material is slowed to a point that’s below the speed at which the material breaks or otherwise degrades. For most materials, the velocity range at the dense-phase system’s start can be as low as 400 fpm. The velocity at the system’s destination is always a function of the system’s pressure drop. Because the conveying air is compressed at the system’s start, the air will expand as it moves toward the conveying line’s end, and the velocity will increase accordingly. The terminal velocity (velocity at the system’s destination) can vary in a dense-phase system but rarely is designed to exceed 2,000 fpm. On the other hand, in a dilute-phase system, the starting velocity can be about 3,500 fpm and the terminal velocity can reach 9,000 fpm.

Phase diagram. A phase diagram illustrating the relative pneumatic conveying phase regions for system pressure drop versus terminal velocity is shown in Figure 1. Each curved line indicates the material’s constant conveying rate in each conveying phase region.

In a dilute-phase conveying system, the material is transported as individual particles are lifted (suspended) by the airstream. When the velocity is reduced from dilute phase to dense phase, a natural phenomenon occurs within the horizontal conveying line: The larger particles can’t sustain the lift and begin to fall to the conveying line’s bottom.
The velocity at which particles fall from suspension in a horizontal conveying line is called saltation velocity. Hence, the best way to identify a dense-phase system is to determine whether the material velocities in the conveying line are designed to operate below the saltation velocity.

Some fine, fluidizable materials can be successfully conveyed just below the saltation velocity. This is desirable because the system consumes minimal energy (by reducing the air mover’s speed) in this operating range. Some system suppliers call this condition two-phase flow (Figure 1) because the conditions inside the conveying line combine dense-phase wave flow (in which material at the line bottom flows in the form of waves) and dilute-phase suspension flow (in which material in the line’s upper portion is suspended in the conveying air).

Many coarse, nonfluidizable materials are conveyed erratically in a pneumatic conveying system when the velocity is slightly below the saltation velocity. This causes the system pressure to change rapidly in what’s called unstable dense phase or the unstable region (Figure 1). These pressure fluctuations accelerate and decelerate the material and cause excessive damage to it.

Further reducing the air velocity will create a natural combination of wave and plug flow (in which the material forms a series of plug-like masses, also called pistons) in the conveying line. In these conditions, the system pressure is much higher and, although it still fluctuates to a degree, it’s controllable and consistent. This is called stable dense phase (or simply dense phase).

**Dense-phase applications**

Many friable, abrasive, and thermally sensitive materials are better handled in dense-phase than dilute-phase pneumatic conveying.

Highly friable materials easily degrade during handling and are more likely to be damaged at high conveying velocities. Whole roasted coffee beans are a good example of a highly friable food product. Unbroken beans are more appealing to the consumer and retain more flavor than broken beans, but the roasted beans are very brittle. A dilute-phase conveying system would produce many broken beans and require additional equipment to separate the broken beans. A lower-velocity, dense-phase system would minimize the number of broken beans.

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Abrasive materials can rapidly wear conveying lines when they’re conveyed at high velocity in a dilute-phase system. Many materials, including many minerals and chemicals, are so abrasive they can wear a hole in a conveying line elbow in just a few weeks. Besides increasing system maintenance costs, line wear can cause particles worn from the line to contaminate the conveyed material. Conveying an abrasive material at lower velocity in a dense-phase system can reduce or eliminate this problem.

Soft plastics such as polypropylene and polyethylene pellets can smear onto a dilute-phase conveying system’s line wall when the material slides along an elbow’s outer wall. The material melts because frictional heat develops as the material contacts the wall, leaving a long, thin layer of melted material on it. The layers build up and eventually peel off the wall in strips called streamers or angel hair that become re-entrained in the conveying air. These quickly build up in the system, forming so-called bird’s nests, which are tangled masses that stop material flow through the line. A dense-phase system’s lower velocity prevents the frictional heat that causes streamers to form. [Editor’s note: More information on preventing streamer formation is available from the author and in sources listed in the later section “For further reading.”]

Even if your material is friable, abrasive, or thermally sensitive, dense-phase pneumatic conveying may not be the best available method for transporting it. In some cases, a material’s physical characteristics can cause problems in the dense-phase system. For instance, a cohesive material such as plastic regrind, a compressible material such as...
rubber crumb, or a hygroscopic material such as starch or titanium dioxide can plug the dense-phase system. To determine how well your material can be conveyed in dense phase, you’ll need to identify its physical characteristics through material testing and, in some cases, run tests of the material in a pilot-plant dense-phase conveying system.

In fact, if the main reason you’re considering using dense-phase conveying is other than to prevent material breakage, conveying line wear, or streamer formation, you should choose a dilute-phase conveying system. The dilute-phase system is less costly to install and easier to control, and it requires less operator training and less maintenance.

Also be aware that despite the dense-phase system’s lower velocity, the system isn’t always more energy efficient than an equivalent dilute-phase system. To be sure a dense-phase system is right for your application, discuss the pros and cons of both systems with your system supplier or a qualified pneumatic conveying consultant.

**Designing for troublefree dense-phase conveying**

A dense-phase conveying system is complex. Many operating problems with the dense-phase system occur because those who design and operate the system don’t plan well, don’t have adequate experience, or don’t understand how dense-phase conveying works. When the dense-phase system is applied properly, designed correctly, commissioned by a qualified startup engineer, and operated and maintained properly, it can work well for many years.

To help your system operate successfully, make sure that you thoroughly understand your application data, choose appropriate system equipment and design options, and provide adequate operator training.

**Application data.** The more information you gather about your application and total process, the more likely your system designer will be able to design the dense-phase conveying system to properly handle them. Because the dense-phase system is stable only within a narrow window of operating conditions, it isn’t as flexible as a dilute-phase system in handling various material conveying capacities, materials or material grades with dissimilar physical characteristics, material temperatures, and other variables. You must know each of these variables before designing the dense-phase system to ensure that it can handle them.

While the system designer can build in some flexibility to handle these variables, the designer must design the system specifically for your application. This means the designer needs to understand your total process — the process leading into and out of the system — and each of your process requirements in detail. For instance, venting and leakage into and out of the system — and each of your process variables, the designer must design the system to handle these variables, the designer must design the system to handle the high-pressure rotary airlock feeder installed at your conveying system’s material pickup point typically results in the loss of 30 to 50 percent of the total air consumed by the conveying system. If there’s enough headroom under the material pickup point, you may be able to install a pressure vessel (also called a pressure pot) in place of the rotary airlock feeder to feed material into the system, thereby reducing air losses and saving energy and operating costs.

**System equipment and design options.** Many equipment and design options are available for the dense-phase conveying system. For instance, your material can be fed into the system via a high-pressure rotary airlock feeder, one pressure vessel, two stacked or side-by-side pressure vessels, or other equipment. Your system’s conveying air (or other gas) source can be a screw compressor, a piston compressor, your plant air supply, or another source.

The airflow-control device, the heart of the dense-phase system, must be flexible and accurate.

**Operator training.** Once the system is designed, the operator must be fully trained by the system supplier to understand how the dense-phase system works. This allows the operator to troubleshoot and correct any conveying problems. Poor training can lead to poor system performance as problems such as low or high airflow go unnoticed or improperly diagnosed. Be aware that operator training is typically an added cost not included in the supplier’s bid for your system package and that training quality and completeness can vary by supplier.

**Troubleshooting your dense-phase system**

Many dense-phase conveying systems perform well, but controlling the system is complex and this leads some operators to complain about problems. Common ones include line plugging, excessive material breakage, failing
to make the design conveying rate, and destruction of the conveying line supports.

Why is this type of conveying system plagued by so many problems? Most complaints about dense-phase conveying stem from the system’s failure to convey in stable dense phase because the conveying airflow rate is either too high or too low. Determining which is the case with your system and how to get back to the correct airflow rate depends on your system’s configuration. Consult your system supplier or a qualified consultant for help in fixing these problems.

**Line plugging.** Line plugging due to too much or too little airflow is the most common problem with dense-phase conveying systems. If the conveyed material is permeable, such as with pellets, line plugs are typically caused by too little airflow. If the material is a fine powder, however, the line can plug from either too much or too little airflow. For this reason, the operator must know at all times how much air is being supplied to the system. In some cases, it can help to install more airflow monitors than were originally supplied with the system or to add more sophisticated (and thus more costly) monitors that can trigger an operator alarm in a high- or low-airflow condition. In any case, talk with your supplier or a qualified consultant to determine how best to prevent line plugs in your system.

**Excessive material breakage.** Material breakage is a direct function of the material velocity in the conveying system and typically results from too much airflow in the system. In addition to reducing the airflow, consult your supplier or a consultant to see if other modifications to the system can help reduce breakage.

**Failure to make design conveying rate.** Not reaching the system’s design conveying rate usually happens when, for some reason, the system has reached its maximum conveying pressure or pressure drop. A major cause is that the conveyed material isn’t behaving as the system supplier expected it to. Because of the nature of dense-phase conveying, the pressure in the conveying line greatly depends on the material’s physical characteristics and the conveying rate. Friction between the material and the conveying line wall creates a much higher pressure in the conveying line in a dense-phase system than in a dilute-phase system. Thus small changes in friction coefficients between the line surface and the material (caused by adhesive forces) can have large effects on the conveying pressure. The way particles in the material interlock with other particles (caused by cohesive forces) as they move through the line also has a large effect on the system pressure drop. While these adhesive and cohesive forces aren’t the only variables affecting the system’s conveying pressure, they’re the major ones. Most conveying-rate problems can be prevented by correctly characterizing your material’s properties. If your installed system isn’t meeting its design conveying rate, ask your supplier or a qualified consultant to make an on-site inspection to evaluate the system’s equipment and operating conditions and determine how to solve the problem.

**Destruction of conveying line supports.** In a dense-phase conveying system, the conveying line can shake enough to break its steel supports. This is because the system’s natural conveying pattern is moving plugs (or waves) of material through the line. When a plug changes direction in an elbow, it produces two reaction forces on the line at that point: An impact force from the plug hitting the elbow, because the plug wants to move in a straight line, and a centrifugal force induced into the line and its supports as the mass of material changes direction.

Establish periodic maintenance inspections of the dense-phase conveying system to ensure that the system is operating in stable dense phase.

Both reaction forces occur at every elbow and each time a plug hits each elbow. The cycle time between plugs is typically about once every 30 seconds. Thus, if the system runs continuously for 24 hours per day, a plug hits each elbow over 1 million times per year. In general, larger conveying lines sustain larger-magnitude reaction forces, but most problems caused by these forces can affect lines as small as 3 inches in diameter. The line shaking that results from the reaction forces can eventually damage the line supports.

Follow these two steps to prevent line support damage before the system is installed:

1. Give special attention to designing the line supports during the system design phase. The system supplier should provide data for the reaction forces’ expected magnitude to the design engineer who will design the conveying line and its structural steel supports. The engineer must use this information to determine the supports’ fatigue levels, bending moments, and stresses and to develop line anchoring designs and steel support configurations that can handle them. Be aware that the costs of engineering and installing stronger pipe supports and additional supporting structural steel for a dense-phase system with 6-inch-diameter or larger conveying line can greatly increase the system’s overall cost.

2. Establish periodic maintenance inspections of the dense-phase conveying system to ensure that the system is operating with the correct airflow. This will prevent the system from operating in unstable dense phase, which can induce dramatically larger forces into the line supports and, if left unattended, accelerate the supports’ destruction.
If your installed system exhibits line support damage, stop or limit the damage with any of these methods:

- Add rigid supports to the entire conveying line to eliminate line movement and allow the line and supports to absorb stresses without fracturing any system components.

- Rather than use rigid supports for the conveying line, allow the entire conveying line to “float” and move by resting the conveying line on steel supports covered with a vibration-absorbing material such as neoprene or rubber to dampen the line movement. This method also reduces the total amount of structural steel required to support the system.

- Combine these methods by fixing the straight conveying line sections with rigid supports and using vibration-absorbing materials at the elbows where reaction forces are generated.

**For further reading**

Find more information on dense-phase conveying in articles listed under “Pneumatic conveying” in *Powder and Bulk Engineering*’s comprehensive “Index to articles” (in the December 2002 issue and at www.powderbulk.com).

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