Understanding dense-phase conveying

In the world of pneumatic conveying, there are two system types: dilute- and dense-phase conveying. Dilute-phase conveying is the most common of these two systems, due in part to its relatively straightforward design. If designed correctly, a dilute-phase conveying system can provide reliable and flexible service. However, dilute-phase conveying requires a lot of gas and operates at relatively high gas and solids velocities. As a result, particle attrition, floss and fines, and erosion can be an issue, as can higher utility costs such as additional blower capital and operating expenses.

One solution to these issues is to instead use a dense-phase conveying system. In dense-phase conveying, the gas velocity is much lower, usually around 20 ft/sec, well below the saltation velocity (the gas velocity where particles begin to drop out). With the superficial gas velocity below the saltation velocity, and particles move much slower in dunes or plugs. Figure 1 illustrates this particle flow behavior as gas velocities are decreased in a pipeline. At very high velocities, particle flow is homogeneous and indicative of the flow profiles with dilute-phase conveying. As the superficial gas velocity decreases below the saltation velocity (which is discussed further later in this article), particles begin to drop out and cluster together, as shown in Figure 1. At some point, the particles move along the pipeline as moving dunes for fine particles or slugs for larger particles. Lowering the gas velocity even more causes the particles to move through the pipeline as extruded flow. If the gas velocity gets too low, then no solids flow will occur.

With particles moving at lower velocities and as dunes or slugs, attrition, floss and fines generation, and erosion are minimized. Lower gas volumetric flowrates and smaller pipe diameters are used for moving the same amount of material, so operating costs are typically lower. For dense-phase conveying, about 1 cubic foot of gas is needed to move 2 pounds of material. For dilute-phase conveying, 35 cubic feet of gas is needed to move 2 pounds of material. Furthermore, the lower gas and solids velocity of dilute-phase reduces the volatiles stripping of the solids, which is certainly a consideration for preserving aroma or limiting oxidation.

However, dense-phase conveying is not without its challenges. Not all materials do well in a dense-phase conveying system and many are prone to plugging. Dense-phase systems also require higher pressure to move the materials. While dilute-phase conveying lines typically operate with an initial pressure below 15 psig, dense-phase conveying lines operate above 15 psig. Also, dilute-phase conveying lines can be operated over a much longer distance than dense-phase conveying lines. Due to gas compressibility and impractical pressure drops, dense-phase conveying lines longer than 500 yards are rare. The design and operation of a dense-phase conveying line is specific to the material and application. Understanding the fundamentals of dense-phase particle flow is a good start with such a design.

Fundamentals of dense-phase conveying

Dense-phase conveying is a relatively young technology. It was developed at Cambridge University in 1970. Dilute-phase conveying was developed in the 1880’s. Researchers proved that reliable gas-solid flow can be achieved when gas velocities are below the saltation velocity or the point where solids drop out of the gas flow, as shown in Figure 2. Saltation is the point where gravity starts to dominate over the drag forces, aka where the frictional effects of the gas flowing over the particles no longer has enough force to keep the particles in suspension. The saltation point coincides with maximum throughput but with consequences. If your material is dropping out, some of that material can remain in the line for a very long time. As a result, dense-phase pneumatic conveying systems can operate at velocities either higher or lower than the saltation velocity. At higher velocities, all the material is moving forward but as a more dilute suspension. At lower velocities, particles settle out enough to form clusters, dunes, or slugs. There needs to be enough material that drops out to form a gas-flow resistance or pressure head to sufficiently push the material forward as a bulk ensemble.

This is why not all materials are suitable for dense-phase conveying. Materials that are good candidates for dense-phase conveying tend to have low gas permeabilities as these material can develop the flow resistance and pressure head needed to move the bulk ensembles forward. If the permeability is too high, the gas will flow through the material and
particles can reduce erosion, as well. Since cohesive forces or other factors are at play here with the larger material particles in dense-phase conveying lines, there are several factors to consider. Changes in temperature, pressure, and moisture levels can significantly impact the level of the forces on the material, and that could negatively affect the operation of a dense-phase conveying line. An increase in moisture levels, even a subtle one, with the dense-phase conveying of plastic particles can result in a reduction of electrostatic forces. This would reduce the level of clustering; and, with the permeability of this material being so high, could result in plugging.

**Dense-phase conveying line components**

As shown in Figure 3, the dense-phase conveying line starts with a feed tank, such as a hopper, that can be pressurized from the top or, alternatively, from the cone region (or both). Pressurizing from the cone region can provide a better flow as less compaction is likely to occur in the feed tank. A rotary valve below the feed tank is used to feed the material into the conveying line where secondary gas is used to move the material through the line. Unlike dilute-phase con-
Dense-phase conveying lines, the options for feeding a dense-phase conveying line are few. With the higher pressure in the dense-phase conveying line, nonmechanical valves and screw feeders are generally not an option. Also, rotary valves can promote the slug flow behavior needed for effective dense-phase conveying.

Other options are available for promoting slug flow behavior in a dense-phase conveying line. As shown in Figure 4, an air knife can be used to send gas pulses to interrupt the solids flow and generate better-formed slugs or better-developed extrusion flow. If the conveying line is long, an air knife may not be enough, and booster valves can be used. An array of these valves can be aligned along the distance of the conveying lines and are supplied by another gas source. As a slug of material moves by the valve, the local pressure decreases, which opens the valve. The valve opening results in a fresh injection of air that helps maintain the slug of material and reduce the possibility of plugging.

Unlike dilute-phase conveying, the options for the type of bends that can be used in dense-phase conveying are limited, as well. Typically, long-radius bends with an r/D (radius of bed vs. pipe diameter) of 10 or greater are used. Bends with a shorter radius could result in too high a pressure drop or disrupt the slug or dune behavior, both of which could result in plugging.

Of course, none of these components are useful unless the correct design parameters are obtained. In the design of a dense-phase conveying line, the pressure drop, minimum pipe diameter, and minimum gas supply need to be determined first. The design procedure consists of determining the pipe size based on the solids flux requirements; calculating the minimum gas requirements based on the pressure drop per unit length of conveying lines (equations exist but experimental validation is a good idea); and determining the total pressure drop for all the horizontal lines, vertical lines, and bends for sizing blower capacity.

**Troubleshooting**
As with most unit operations in particle technology, a lot can go wrong, and the same is true for dense-phase conveying lines. Plugging and hammering are the two biggest issues. As noted above, plugging is the result of permeability changes or other factors that can affect the development and stability of slugs in the conveying line. If the slugs are becoming shorter, the increased permeability could destabilize the solids flow. If the slugs become longer, the force of the gas against the slug may not be strong enough to move the slug forward. Boosters can help preserve a stable slug flow and minimize plugging issues by providing a gas push as the slug passes by each booster valve. Hence, slug size is externally controlled. It’s definitely a brute force approach toward dense-phase conveying.

If the cohesive forces or other factors become too strong or too weak, plugging can be an issue, as well. Temperature and moisture levels both have a significant impact on cohesive forces. If such forces are needed for stable dense-phase conveying operations, then controls need to be in place for both the temperature and moisture levels in the conveying gas.

Another issue with dense-phase conveying is hammering. Having large and dense slugs of material moving down your conveying lines could put significant force on the bends. One of the reasons the bends need to have a long radius is because of this force. Such a force is powerful enough to move a conveying line several feet in one direction and back. If the supports are not designed for this force and movement, containment loss will be an issue. As a result, dense-phase conveying lines are supported with support rollers, mechanical or hydraulic snubbers (dampeners), spring hangers, and more.

If vibrations or hammering is too severe, then plug decelerators may need to be used. Plug decelerators bleed out enough gas to slow down the slug but not enough to cause plugging. As a result, the forces on the bends are reduced. However, operating a line with plug decelerators is a bit of an art form.

**Final note**
Dense-phase conveying can be a viable solution but only if the material technology, a lot can go wrong, and the same is true for dense-phase conveying lines. Plugging and hammering are the two biggest issues. As noted above, plugging is the result of permeability changes or other factors that can affect the development and stability of slugs in the conveying line. If the slugs are becoming shorter, the increased permeability could destabilize the solids flow. If the slugs become longer, the force of the gas against the slug may not be strong enough to move the slug forward. Boosters can help preserve a stable slug flow and minimize plugging issues by providing a gas push as the slug passes by each booster valve. Hence, slug size is externally controlled. It’s definitely a brute force approach toward dense-phase conveying.

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rial is suitable. For fine materials, the permeability needs to be low. For large materials, the permeability can be higher provided the material has cohesive, or similar, behavior to form and stabilize slugs. Proper feeding of the conveying line is also important and you should consider adding air knives or boosters to your line for more problematic materials. One precaution reminder about dense-phase conveying lines is that operators need to be aware of hammering. The conveying line is going to move back and forth, and your supports need to be designed for such movement. PBE

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**References**

1. For more information, visit Powder and Bulk Engineering’s Article Archive for past Particle Professor columns and other articles on pneumatic conveying.

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**For further reading**

Find more information on this topic in articles listed under “Particle analysis” and “Pneumatic conveying” in Powder and Bulk Engineering’s comprehensive article index in the December 2017 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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