What is dense-phase conveying?

Dense-phase pneumatic conveying is harder to define than dilute-phase conveying — in fact, we can define dense-phase conveying as any conveying that *isn’t* in dilute phase! And the simplest way to define dilute-phase conveying is this: Material conveyed in dilute phase doesn’t settle on the bottom of a horizontal conveying line but instead remains in motion, suspended at about the conveying line’s centerline while moved along by the conveying air’s drag forces. (Find more information on pneumatic conveying phases in the July 1991 “Pneumatic points to ponder...” column.)

The difference between dilute-phase and dense-phase conveying is illustrated by a graphical representation of conveying data called a *phase diagram*. The phase diagram can plot either conveying capacity versus airflow volume or pressure versus airflow volume, and looking at both types yields a more complete picture of the conveying phases. When we plot conveying capacity versus airflow volume for an application conveying plastic pellets through a 2-inch conveying line, we get the phase diagram shown in Figure 1a. When we plot the same data as pressure versus airflow volume, we get the phase diagram shown in Figure 1b. The *saltation velocity* (that is, the conveying velocity at which material falls out of suspension and settles on the bottom of the horizontal conveying line) occurs at the peak in Figure 1a and the valley in Figure 1b, which for this application is at 100 scfm. Dense-phase conveying is any conveying that occurs below the saltation velocity. In dense phase, material can move in any of several ways generally categorized as either *two-phase flow* or *piston flow* (also called *pulsed-piston flow*), as shown in Figure 2.
Long-standing confusion
When the term dense-phase for this form of conveying first became popular in the late 1970s, many bulk solids processors and handlers were excited about what dense-phase conveying offered: lower conveying velocities that resulted in less equipment wear and less particle attrition. But few users really knew what they were getting with dense-phase conveying, and this hasn’t changed.

The main confusion is about what operating pressure a dense-phase conveying system requires. Users wonder: Can I have dense-phase conveying in a system that operates at a pressure of 7 psig? Can I have dense-phase conveying in a vacuum system? The answer to both questions is Yes! Dense-phase conveying doesn’t depend on operating pressure — it depends on conveying velocity and material loading. Dense-phase conveying occurs when the conveying velocity is less than the material’s saltation velocity and the material loading is relatively high. Another way of looking at it is that dense-phase conveying occurs at the left side in the Figure 1 phase diagrams, while dilute-phase conveying is at the right.

Conveying phase and material characteristics
Users also ask: What’s going on in my conveying line during dense-phase conveying? I hear material pistons or slugs passing. I see the conveying line shaking. But what’s actually happening in there?

Most of what happens in a dense-phase conveying system depends on the conveyed material’s characteristics. By using the Geldart model, as shown in Figure 3, we can predict how a material will act in a dense-phase conveying system based on the material’s characteristics. In the model, materials are classified into four groups, A through D, depending on their particle density and size. As you can see in Figure 3, lightweight materials fall into the model’s lower portion, below the particle density line at 1,000 kg/m³, while heavy materials fall above this line. Likewise, smaller particles fall toward the left side, and larger particles toward the right. As in Figure 4, and would result in line plugs.

Group C materials. At the Geldart model’s left, very fine materials are classified as Group C. Even though they’re dry, these materials feel sticky and moist to the touch. Typical examples are paint pigments (such as titanium oxide), lead oxide, and finely ground calcium carbonate for use as a sorbent. A Group C material doesn’t like to fluidize and tends to coat the conveying line wall, making it a candidate for nonpermeable-piston flow (Figure 2b). In this conveying type, it’s important to keep the pistons from becoming too long, because pushing the long pistons through the line would require excessive air pressure, as shown in Figure 4, and would result in line plugs.

Many methods can be used to limit the piston length. One approach is to use a small-volume pressure tank that discharges all of its contents into the conveying line as one piston. This limits the piston length because a single tank discharge injects all the mate-

Figure 2
Dense-phase conveying types

<table>
<thead>
<tr>
<th>a. Two-phase flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airflow</td>
</tr>
<tr>
<td>$P_1$</td>
</tr>
<tr>
<td>$P_2$</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>b. Nonpermeable-piston flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airflow</td>
</tr>
<tr>
<td>$F$</td>
</tr>
<tr>
<td>$P_1$</td>
</tr>
<tr>
<td>$P_2$</td>
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</tbody>
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<tr>
<th>c. Permeable-piston flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airflow</td>
</tr>
<tr>
<td>$F$</td>
</tr>
<tr>
<td>$P_1$</td>
</tr>
</tbody>
</table>

*Note: $P_1$ is operating pressure; $P_2$ is greater than $P_1$; $F$ is the friction force between the piston and the conveying line wall.

Figure 3
Geldart model

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rial from the tank into the line. After this piston exits the line, the pressure tank is refilled with material and the process is repeated.

Another method is to use supplementary air in the form of air boosters to limit the piston length in the conveying line. If a piston becomes too long and not enough air pressure is available to move it, it forms a temporary line plug. But if another source—a bed booster—introduces air into the middle of this plug, it will be cut into two shorter pistons that will then move through the line. If we don’t know where the long piston (the temporary line plug) will form in the line, we can place the boosters at points that match the desired maximum piston length. Then, whenever a longer piston forms, a booster will limit its length by injecting air into it.

Because a Group C material doesn’t fluidize, the air boosters are needed only to limit the piston length or remove line plugs (or both). Even so, some suppliers design systems with continuously operating air boosters.

**Group A materials.** At the right of Group C on the Geldart model are Group A materials, which are fluidizable. Typical examples are wheat flour, fly ash, Portland cement, ground calcium carbonate, and alumina. A Group A material behaves like a fluid when mixed with air. Once the material has been fluidized it’s hard to compact it, and after it is compacted, such as in a feed hopper, it readily falls apart and becomes fluidized again when mixed with air during pneumatic conveying.

Group A materials can be conveyed very well in two-phase flow, in which the material is introduced into the flowing conveying air in the line rather than injected as a compacted piston, as in piston flow. Introducing the material into the airflow fluidizes the material, which then settles on the bottom of the horizontal line. However, because the air flows over the settled material, the material moves like ocean waves that aren’t controlled and form at random, depending on the depth of fluidized material and the air velocity above it (Figure 2a).

If this material remains fluidized for a time (called air retention time), it will flow for a long distance in this condition. For instance, a material with a 30-second air retention time conveyed at 2,000 fpm will remain fluidized for a distance of 1,000 feet. Each time the conveying line changes to a vertical direction, the material will refluidize because it becomes suspended in the now-vertical airflow, allowing conveying to continue another 1,000 feet. In a long conveying system, using one (or more) vertical line section can keep the material fluidized throughout the system; however, each vertical section requires two 90-degree bends, which will increase the system’s equivalent line length by about 40 feet.

**A caution:** Air boosters are sometimes used in an attempt to keep the material in a fluidized state for two-phase flow. Positioning the boosters at the bottom of the horizontal line will allow the injected air to bubble upward through the material to keep it fluidized; however, injecting the air at this location will quickly plug the boosters. This leads many users to install the boosters on top of the horizontal line, where the air injected downward into the material not only doesn’t fluidize it, but tends to compact it, so this usually isn’t a solution.

**Group B materials.** Still farther to the Geldart model’s right are Group B materials, which are coarser than the fluidizable Group A materials. Typical Group B materials are sugar and sand. Because of its larger particle size, a Group B material requires more air to become fluidized and has a shorter air retention time, causing it to deaerate quickly. These qualities make a Group B material the most challenging material to convey pneumatically. The material is often abrasive, friable, or moisture- or temperature-sensitive, as well, adding to the challenge.

For a distance under 300 feet, a Group B material can be conveyed either in two-phase flow or nonpermeable-piston flow (Figure 2). In a longer conveying line, the material will usually form line plugs near the line’s end. Depending on the application, this problem can be overcome by using air boosters along the line, changing the line direction from horizontal to vertical, or increasing the conveying velocity.

However, increasing the conveying velocity won’t work if the material is abrasive or if it can be degraded at higher velocity. One option that may work for a material that isn’t abrasive and doesn’t degrade easily is low-velocity dilute-phase conveying.

**Group D materials.** At the Geldart model’s far right are Group D materials, which have a larger particle size than the others and can’t be fluidized. Common examples are plastic pellets, corn, and wheat. The material can’t be compacted into a nonpermeable piston, but it can form a permeable piston that allows air to pass through (Figure 2c).

Because the pistons are permeable, a Group D material seldom forms line plugs. However, when conveyed below the saltation velocity, the material will form waves or plugs (or both).
of random length and frequency, and little can be done to control this.5

**Group C-D materials.** In some applications, the conveyed material contains both Group C and D materials. Such a material has a wide particle size variation, containing fines down to 1 micron (Group C) and large particles (Group D). The fines fill the voids between the large particles, creating nonpermeable pistons that can form line plugs in very long horizontal line sections.

A Group C-D material also tends to segregate, presenting another conveying problem. For instance, a material containing particles ranging between 325 mesh and ¼ inch will segregate in a feed hopper. When discharged into a tank, the material will segregate. Then, when the material is fed from this tank into a pressure system, the material can contain all large particles one moment and mostly fines the next. This means that the conveying system must be able to handle all possible combinations of flow: two-phase (fluidized), permeable piston, and nonpermeable piston. Designing such a system is challenging.

—**P.E. Solt and J.D. Hilbert**

**References**

1. Find topics, issue dates, and page numbers for previous “Pneumatic points to ponder...” columns in Powder and Bulk Engineering’s comprehensive article index in the December 2011 issue and at www.powderbulk.com. For more information, see “For further reading.”

2. Find more information on saltation velocity in the November 1991 column and on dense-phase conveying types in the March 2003 column.

3. Read the March 2011 column for more information on the Geldart model.

4. See the July 2008 column for an in-depth look at problems with conveying sugar, one of the most difficult-to-convey Group B materials.

5. For further detail, see the July 1991 column.

**For further reading**

Find more information on dense-phase conveying in articles listed under “Pneumatic conveying” in Powder and Bulk Engineering’s comprehensive article index (in the December 2011 issue and at www.powderbulk.com) and in books available on the website at the PBE Bookstore. You may also purchase a CD containing all previous “Pneumatic points to ponder...” columns through 2008, or individual columns, at www.powderbulk.com.

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**Solt and Hilbert to present at PBE’s 2013 Midwest Conference & Powder Show™**

Paul E. Solt and Jack D. Hilbert will present information on pneumatic conveying at PBE’s Midwest Conference & Powder Show™ in Columbus, Ohio, May 21-23, 2013.