Factors that affect pneumatic conveying — Part I

In past “Pneumatic points to ponder…” columns we’ve frequently addressed the issue of material properties. In fact, when I have the opportunity to meet people who have read our columns or participated in webinars or sessions at industry trade shows, people will often ask if the material properties are really all that important.

The answer is a resounding — and emphatic — yes!

A material’s bulk density and particle density, as well as its particle size distribution, are some of the main physical properties with which we deal on a daily basis when working with bulk solids and designing pneumatic conveying and other handling systems. Knowing these parameters, we can go to the Geldart Model, which classifies powders according to their fluidization properties, and determine in which classification group the material lies. This gives us a very good start on our system design and equipment selection.

Other system and material properties that need to be considered include temperature and moisture, as well as material explosibility, chemical reactivity, and toxicity. In this two-part column, we look at these factors and analyze their effect on choosing equipment and designing a system. In Part I, we’ll discuss temperature and moisture.

**Effects of temperature and moisture**

The conveying air temperature in a pneumatic conveying system can adversely affect the conveyed material. You typically don’t have to consider this with a vacuum conveying system because the conveying air usually comes from an ambient area or room. In a pressure conveying system, the adiabatic heat of compression raises the air temperature, as shown in Table 1.

Many materials soften when exposed to these elevated temperatures. Some common examples are low-melting-point plastics and sugar. To convey these materials in a pressure conveying system, you must reduce the air temperature. This can be done using an air-to-water heat exchanger, as shown in Figure 1. The conveying air flows through the heat exchanger, passing over water-filled tubes that cool the air before it contacts the conveyed material. Air-to-air heat exchangers, shown in Figure 2, are also available as an option.

<table>
<thead>
<tr>
<th>Air inlet temperature (°F)</th>
<th>Operating pressure (psig)</th>
<th>Air discharge temperature (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>6.0</td>
<td>91</td>
</tr>
<tr>
<td></td>
<td>10.0</td>
<td>119</td>
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<tr>
<td></td>
<td>15.0</td>
<td>150</td>
</tr>
<tr>
<td>80</td>
<td>6.0</td>
<td>135</td>
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<tr>
<td></td>
<td>10.0</td>
<td>165</td>
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<td></td>
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<tr>
<td>120</td>
<td>6.0</td>
<td>179</td>
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<tr>
<td></td>
<td>10.0</td>
<td>212</td>
</tr>
<tr>
<td></td>
<td>15.0</td>
<td>248</td>
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</tbody>
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* Note: All values are approximate
Moisture in the conveying air frequently causes line plugs, material buildup inside the conveying line, and changes in the material’s physical characteristics (especially when the material is hygroscopic). To handle moisture problems, remember that in a typical conveying system the air usually contacts the material for a very short time — generally a few seconds at best (calculated by dividing the conveying line length by the average material velocity). With such a short reaction time, there’s usually no change in the material’s moisture content.

Understanding how moisture affects and behaves in the conveying air can be confusing, so the following examples and information should be useful in determining what moisture problems you might have and how to correct them.

Table II is a partial listing of specific volume saturation (in cubic feet of air per pound of water vapor). This is the volume of air you need at a given temperature to hold 1 pound of water vapor. These values can be obtained from psychometric charts or steam tables.

Using a specific-volume saturation table is relatively simple, as shown in the first of the following five examples of conveying in different types of systems and under different conditions.

Example #1 — standard air in a pressure or vacuum conveying system: Air at 70°F and 100 percent humidity requires 868 cubic feet of air to hold 1 pound of water vapor. If we have a conveying system using 1,000 scfm, we’re taking into the system 1.1 pounds of water/min:

\[
1,000 = 1.152 \text{ pounds of water/min}
\]

Example #2 — vacuum conveying system: Assuming no temperature change but air expansion due to the vacuum, the air volume (in standard scfm) would increase as the air flows through the conveying line. Assuming a vacuum of 10 inches mercury, the actual air volume (acfm) would increase by the absolute pressure ratio to 1,500 acfm:

\[
1,000 \times 30 / (30 - 10) = 1,500 \text{ acfm}
\]

The 1,500 acfm of air could hold 1,728 pounds of water/min:

\[
1,500 / 868 = 1.728 \text{ pounds of water/min}
\]

But, because the system only ingests 1.52 lb/min, the relative humidity (actual water vapor per saturation water vapor) would be reduced to 66.6 percent:

\[
1.152 / 1.728 = 66.6 \text{ percent relative humidity.}
\]

So, in a vacuum conveying system, we can see that even without a temperature change, the relative humidity decreases as the air expands in the system.
Example #3 — pressure conveying without cooling: If we take 1,000 cfm of air at 70°F and 100 percent humidity and supply the air through a blower that’s discharging at 10 psig, what would the air’s relative humidity be at the blower discharge?

From Table 1, we estimate the blower discharge air temperature to be 155°F. The specific volume saturation at 155°F is about 87 cubic feet. Thus, when correcting for pressure (by using the absolute pressure ratio 14.7/24.7) and correcting the temperature 615/530), the 1,000 scfm would be 690 acfm.

With a specific volume saturation of 87 cubic feet, the air under these conditions could hold 79 pounds of water/ min:

\[
690 / 87 = 7.93 \text{ pounds of water/min}
\]

However, because only 1.152 pounds of water are present, the relative humidity is 14.5 percent:

\[
1.152 / 7.93 = 14.5 \text{ percent}
\]

Example #4 — pressure conveying with cooling: If we take 1,000 cfm of air at 70°F and 100 percent humidity and supply the air through a blower that’s discharging at 10 psig, what would the air’s relative humidity be if we cooled the air through a heat exchanger to 100°F at the 10 psig?

The specific volume saturation at 100°F is 325 cubic feet. The 1,000 scfm, when corrected for pressure (14.7/24.7) and temperature (560.530), would be 628 acfm. With a specific volume saturation of 325, the air in this condition could hold 1.9 pounds of water/ min:

\[
628 / 325 = 1.932 \text{ pounds of water/min}
\]

However, because only 1.152 pounds of water are present, the relative humidity is 59.6 percent:

\[
1.152 / 1.932 = 59.6 \text{ percent}
\]

Let’s assume 1,000 cfm of air is going into the blower at 90°F, the relative humidity is 95 percent, and the blower discharge is at 15 psig and then cooled to 100°F. The specific volume saturation at 90°F is 468. At 100 percent humidity, the 1,000 cfm could hold 2.1 pounds of water/ min:

\[
1,000 / 468 = 2.136 \text{ pounds of water/ min}
\]

But because the relative humidity is only 95 percent, the actual water weight is 2.03 pounds:

\[
2.136 \times 0.95 = 2.03 \text{ pounds of water/ min}
\]

At the cooled discharge conditions of 15 psig and 100°F, the air volume is 503.9 acfm:

\[
1,000 \times 14.7 \times 560 / 29.7 - x 550 = 503.9 \text{ acfm}
\]

With a specific volume saturation of 350 at 100°F, the maximum amount of water that can be held in the air is 1.4 pounds/ min:

\[
503.9 / 350 = 1.439 \text{ pounds of water/ min}
\]

But 2.03 pounds of water/ min enter the conveying system, so the amount of water that will condense in the conveying system on either the conveying line walls or on the material is 0.5 pounds:

\[
2.03 - 1.439 = 0.591 \text{ pounds of water/ min}
\]

Note: In example #4, we assumed the air was cooled to 100°F by a heat exchanger. If the air wasn’t cooled but the conveyed material was only 100°F, that would have a similar effect. This is because the air would be cooled by the cold material and moisture would condense on the material surface just as moisture forms on a mirror in a steamy bathroom. Thus, it’s important to ensure that your conveyed material’s temperature isn’t below the air’s dew point under any condition encountered in the system. This dew point is the temperature at which the air will be fully saturated.

Example #5 — the dew point factor: In example #3, which concerned pressure conveying without cooling, we calculated that the 690 acfm of air contained 1.152 pounds of water/ min or had a relative humidity of 14.5 percent.

If the air volume divided by the specific volume saturation equals the amount of water that can be held, we can obtain the 100 percent relative humidity temperature (dew point) by dividing the air volume (in acfm) by the water content and then finding the temperature that has that specific volume saturation.

An air volume of 690 acfm containing 1.152 pounds of water/ min has a relative humidity of 14.5 percent. Dividing the air volume (in acfm) by the water content, we obtain the desired specific volume saturation of 598:

\[
690 / 1.152 = 598
\]

By interpolation from Table II, we see that the dew point is about 72°F. That means that if we were conveying material cooler than 72°F, moisture would condense on the material’s surface.

Choosing a dryer
If you need to dry the air to control moisture in your conveying system, selecting the right equipment can be challenging. Dryer types include refrigerant-reheat and desiccant.

In the refrigerant-reheat unit, the air is cooled to a desired temperature, which precipitates all the moisture out of the air that won’t remain as a vapor above that temperature. The moisture is filtered completely out of the air, and then the air is reheated and supplied to the conveying system. The temperature to which the air is cooled is, in essence, the air’s dew point at that pressure. As the air is heated, the specific volume saturation increases, reducing the
air’s relative humidity. As the air expands in the conveying system, the volume increases and the dew point lowers or the relative humidity further decreases, or both.

In a desiccant dryer, the conveying air is passed over a desiccant material that adsorbs the air’s moisture. Temperature isn’t the controlling point but as our calculations in the previous examples show, the more water that’s removed, the lower the relative humidity and the dryer the air.

By selecting the right dryer — either refrigerant-reheat or desiccant — you can remove the required amount of moisture from the air entering the conveying system, which will maximize the relative humidity at any point in that conveying system. As always, please feel free to send me any questions you may have.

Note: The next “Pneumatic points to ponder…” will cover material combustibility and toxicity, as well as how a closed-loop pneumatic conveying system can affect your conveying operation.

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 2018 issue or the Article Archive at PBE’s website. (All articles listed in the archive are available for free download to registered users.)

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