In this tenth column on the general application of pneumatic conveying, we’ll apply information from previous columns to designing a pressure pneumatic conveying system fed by a venturi. As you read this month’s column, it may be helpful to review related topics in previous columns.1,2

Many readers have requested information about how to design a pressure conveying system in which a venturi feeds material to the system. I’ll answer that question in this month’s column.

Information in past columns has covered conveying system types (such as dilute phase and dense phase) and methods for feeding material to these systems. Four particular columns — March 1992, July 1992, March 1994, and November (in the “Solt answers your questions” section) 1994 — provide background information for this month’s column.

Why a venturi?
A venturi (also called an eductor) is simply a flow-constricting pipe or tube with an air inlet, a material inlet (in a section of the venturi that has a narrow diameter), and an outlet. When used as a feeder in a pressure pneumatic conveying system, the venturi is inserted into the conveying line below the feed hopper. The venturi’s air inlet is upstream from the hopper, the material inlet is connected to the hopper discharge, and the outlet is downstream from the hopper to direct flow into the conveying system. In operation, the conveying air flows through the venturi’s air inlet and past the material inlet, creating a vacuum that draws material from the hopper discharge and through the venturi, where it’s entrained in the air before it exits the venturi’s outlet to enter the conveying system.

Using a venturi to feed material to a pressure conveying system is appealing because the venturi has no moving parts and leaks no air. The downside is that, by increasing the air pressure required for conveying, the venturi increases system horsepower requirements.

Some variations
The standard venturi isn’t the only option for feeding material to the system. In another version, the venturi produces a vacuum in a pressure tank, drawing material into the pressure tank from a railcar, silo, or other supply point. When the pressure tank is full, the venturi is bypassed, and the air supply is directed to the pressure tank and conveying line, resulting in a pressure conveying system. In another configuration, the venturi is located near a rotary feeder-airlock that serves as the system’s primary feeder, and the venturi helps to vent air from the feeder-airlock. The venturi sends the air and material that leak from the feeder-airlock — along with some additional air — back to the conveying system, thus providing secondary material feeding while venting the rotary feeder-airlock.

How the venturi works
To understand how the venturi functions, let’s look at the physics governing system pressure: The conveying system pressure is the sum of the static pressure (as measured by a pressure gauge) and the dynamic pressure (as measured by a pitot tube). When you change the conveying line diameter, the air velocity through the line changes. This changes the static and dynamic pressures in the system, ide-
the throat area, and $P_3$ is the conveying line (downstream) pressure.

**Designing a pressure system with a venturi**

To design a pressure conveying system that's fed by a venturi, follow these general guidelines:

1. Design the conveying system with a slightly higher air velocity than in a typical pressure conveying system to ensure that the material isn't saltated (that is, doesn't drop out of suspension and settle on the conveying line's bottom).

2. Design the system to operate in dilute phase.

3. Use a very light material loading — no more than 2 pounds of material per pound of air, or, expressed another way, at least 7 cubic feet of air per pound of material.

4. Design the system to convey at typically 3.5 psig or less pressure for your desired capacity. While not an absolute limit, the reason for sticking to this pressure level will become clear in the following example.

**System design example**

**Determining the required air supply pressure.** If you want to convey 100 pounds of plastic pellets for a distance of 150 feet, at a rate of 100 lb/min, and with a material loading of 7 cubic feet of air per pound of material, you would use 700 cfm of airflow. In a 4-inch schedule 10 conveying pipe, this would produce a system pressure of about 2.4 psig.

**Design the system to operate in dilute phase.**

The pressure upstream from the venturi in a pressure conveying system should be at least four times the downstream pressure to ensure that the system works well. Because this example system requires 2.4 psig, the pressure upstream from the venturi must be $4 \times 2.4 = 9.6$ (or, say, 10) psig. This means the 700-cfm airflow must be supplied to the system at a pressure of 10 psig, which can be easily produced by a rotary-lobe positive-displacement blower.

**Determining the nozzle diameter.**

The final design element is to determine the diameter of the venturi's nozzle. To do this, you'll need to understand the relationship between upstream pressure, orifice (in this case, venturi nozzle) diameter, and airflow. You can find such information in a reference book or other work on airflow, such as "Flow of Fluids through Valves, Fittings, and Pipe," Technical Paper 409, by Crane Valves, Joliet, Ill. The following equation, which is from this source, can help you determine your venturi nozzle's diameter, although you may need to make some allowances for the nozzle's length, angle of approach (that is, the slope of the venturi's inside wall as the air inlet diameter reduces to the nozzle diameter), and other variables:

$$Q/a = K$$

where $Q$ is airflow in cubic feet per minute (cfm), $a$ is nozzle cross-sectional area (that is, nozzle area) in square inches, and $K$ is a constant that can be defined as follows for different pressures:

<table>
<thead>
<tr>
<th>Pressure (psig)</th>
<th>$K$</th>
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<tbody>
<tr>
<td>1</td>
<td>146</td>
</tr>
<tr>
<td>2</td>
<td>203</td>
</tr>
<tr>
<td>3</td>
<td>493</td>
</tr>
<tr>
<td>4</td>
<td>286</td>
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<td>5</td>
<td>321</td>
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<td>6</td>
<td>352</td>
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<td>8</td>
<td>400</td>
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<td>10</td>
<td>450</td>
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<td>12</td>
<td>490</td>
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<td>15</td>
<td>544</td>
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<td>20</td>
<td>635</td>
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<td>30</td>
<td>819</td>
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So, for this example system operating at 10 psig, $K (Q/a)$ is 450. This means that you can multiply 450 by any nozzle's area and get the airflow through that nozzle. Or, in most cases, you can divide the airflow (700 for our example system) by 450 and get 1.555 — the required nozzle area. Then, to determine the nozzle diameter, you must calculate:

$$\pi \times D^2$$

55
To complete the example system’s design, you can designate a venturi nozzle diameter of 1.407 inch. Then you can test the system by discharging all the blower air, at about 10 psig, through this nozzle. If necessary, you can make the nozzle slightly larger to reduce the blower pressure to the desired 10 psig. You can refine the design to improve its efficiency and to eliminate turbulence in the throat area by expanding the venturi’s outlet at a 13-degree angle from the nozzle diameter, as shown in Figure 1.

The pressure upstream from the venturi in a pressure conveying system should be at least four times the downstream pressure to ensure that the system works well.

**Examining the results.** Now that the system design is done, what pressure can you expect to see in this venturi pressure pneumatic conveying system?

- When the hopper discharge is closed, you may see that $P_1$ is 10 psig, $P_2$ is -0.5 psig (1 inch mercury vacuum), and $P_3$ is about 2.4 psig.

In all three cases, the venturi operates with a constant system (upstream) pressure ($P_1$), because that’s a function of only the nozzle diameter. The vacuum in the throat area ($P_2$) is a function of the material entering the venturi and can vary with the feed conditions. The conveying line (downstream) pressure ($P_3$) is a function of the downstream conveying line’s inside diameter, the airflow, and the material feedrate.

**Endnotes**
