Pneumatic points to ponder...

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Material density and pneumatic conveying

In previous columns, we've tried to provide you with useful information on operating your plant's pneumatic conveying system. Some columns have offered tips and recommendations on optimizing system performance and troubleshooting operations, while others have focused more on design aspects. This column presents results from tests performed to identify how bulk density differences between two materials can affect a pneumatic conveying system's design and overall performance.

You've no doubt seen terms used such as a material's bulk density (loose poured density), compacted density, aerated density, and others. In these cases, the material's description basically defines it. For example.

- *Bulk density* is the material's weight per unit of volume when gravity-fed into a receiver that's weighed while including the voids between the particles. Usually, the larger the particle size, the more void space that exists.
- *Compacted density* refers to a material's weight per unit volume after compaction has occurred. In this case, void spaces have somehow been collapsed to the fullest extent possible, allowing more material to effectively fill the same unit volume. Consequently, the compacted density will be a higher value than the bulk density.
- *Aerated* or *fluidized density* is the value of weight per unit volume for a material that's been fluidized to help make it flow better. A gas (usually air) is introduced into the material to give it fluid-like characteristics. Depending on a material's specific behavior, its aerated/fluidized density can be a significantly lower value than its bulk density.

These types of volumetric measurements are important for volumetrically sized equipment, such as bucket elevators and screw conveyors.

A term you likely aren't as familiar with is *particle density*, sometimes referred to as *true density*, which is the weight of an individual particle of material. If you know a material's specific gravity, then you know its particle density as well. If you could take a container of material for which you measured the bulk density and "squeeze out" the void space, leaving only material, it naturally would weigh more than the original material, so particle density is a higher value than bulk density.

Bulk density and dilute-phase pneumatic conveying

When a dilute-phase pneumatic conveying system is designed, "density" information about the material to be conveyed usually is requested. Often, the same system will have to convey materials of different densities.

For many, the idea that a material's bulk density has significant influence on a pneumatic conveying system has been ingrained, but in most formulas for calculating system pressure in dilute-phase systems, density isn't mentioned. For example, equation 11.1 from Zenz and Othmer[1] is a primary reference we've used as a basis for previous columns and system sizing information. It presents a standard formula that calculates pressure drop in dilute-phase pneumatic conveying systems. The formula's terms include gas kinetic energy, particle kinetic energy, gas friction in the pipeline, and a material-loading multiplier. Material density isn't included, so you might conclude that density should have little or no effect.

This equation, however, deals strictly with a horizontal conveying line. The study of particle density in dilute-phase pneumatic conveying systems has revealed two major points to consider:

1. Particle density affects a system's minimum conveying velocity, which is similar to the saltation velocity. Dilute-phase conveying takes place above a material's saltation velocity. Previous columns have talked about how to calculate saltation velocity, the relationship between particle velocity and gas velocity, and particle density has an effect in that relationship.
2. Heavier particles will have a higher *slip velocity*, or speed difference between the conveying gas and actual particle, so particle velocity and kinetic energy will be lower, requiring less total system pressure under identical gas-flow conditions.

Testing procedure

A well-known industry equipment supplier ran tests in its testing facility to study material density's effect on pneumatic conveying. The tests used two identically shaped materials — roughly 1⁄8-inch spheres — with bulk densities of 280 lb/ft^3 (lead shot) and 35 lb/ft^3 (polyethylene pellets), an 8-to-1 bulk density ratio. Both materials were purchased specifically for the tests, and special effort was made to duplicate particle size and shape. The bulk density effect was isolated by obtaining similar data on a full-size conveying loop with minimal outside influences. All the conveying line was horizontal. Layout consisted of a 140-foot straight section, a 90-degree bend, a 25-foot straight section, a 90-degree bend, a 145-foot straight section, a 90-degree bend, and a 20-foot straight section. All bends were 3-foot-radius (long radius) bends. Line lengths were measured to the intercept points.

A weighbelt feeder was used to control the material's feedrate into a rotary airlock. The airlock discharged the material into a 3-inch-diameter, Schedule 40 conveying line. A rotary-lobe blower, driven by a variable-speed drive, provided the airflow. The material was placed in a hopper above the feeder and collected at the conveying line's end in an identical hopper. Hoppers were interchanged and weighed after each test run.

Airflow was calculated from blower data using blower motor speed (rpm) and differential pressure. Airlock leakage air was subtracted from the blower air, resulting in actual conveying air volume. This was occasionally checked by measuring air volume at the end of the conveying system using an orifice meter.

A series of tests were run for each material at a selected feedrate. The air volume was selected to start at a high airflow rate, with subsequent tests conducted at an incrementally reduced airflow rate. The airflow rate reductions were continued until a line plug formed, indicating minimum airflow velocity for each material.

Test results

The resulting test data shows the effects of bulk density on a pneumatic conveying system, with the minimum velocity for dilute-phase polyethylene pellet

Table I

Minimum pickup velocity

Material feedrate (lb/min)	Minimum pickup velocity Polyethylene	Lead	Percent increase	Exponential
100	3,907	5,342	36.7	0.151
150	4,159	5,822	39.9	0.162
200	4,363	6,171	41.4	0.166
250	4,381	6,259	42.8	0.172

Table II

Operating pressure at identical airflow and feedrate

Material feedrate (lb/min)	Airflow (scfm)	Operating pressure Polyethylene	Lead
100	350	3.6	3.1
100	375	4.1	3.3
100	400	4.5	3.6
150	400	5.1	4.2
150	425	5.5	4.4
200	450	6.8	5.2
250	450	7.1	5.9

Table III

Operating pressure at minimum airflow and identical feedrate

Material feedrate (lb/min)	Airflow (scfm)	Operating pressure Polyethylene	Lead
100	240	2.9	-
100	330	-	3.0
150	270	3.9	-
150	380	-	4.0
200	300	5.0	-
200	420	-	4.8
250	315	5.9	-
250	450	-	5.9

Table IV

Minimum air volume required for identical feedrate

Material feedrate (lb/min)	Minimum air volume Polyethylene	Lead	Percent increase
100	240	330	37.5
150	270	380	40.7
200	300	420	40.0
250	315	450	42.8

conveying in the 3,900 to 4,300 fpm range and for dilute-phase lead shot conveying in the 5,300 to 6,200 fpm range. Under identical feedrates and airflow volumes, the required pneumatic conveying system pressure for the lighter material was actually 20 to 30 percent higher than the system pressure for the heavier material.

Pickup velocity

From a study of available saltation velocity data, saltation velocity appears to vary as does material density raised to the 0.55 power. The 8-to-1 density change would suggest a required saltation velocity increase of 3.14-to-1. Table I lists the minimum pickup (conveying) velocity for each feedrate, the percent increase in velocity, and the exponential of the density ratio that would result in the observed change. According to these test results, it would appear that the conveyed material's density doesn't influence the minimum conveying velocity as much as is generally accepted to be the case.

Conveying system operating pressure

Since material density isn't included in the Zenz and Othmer 11.1 equation, you also might think that density has little effect on a pneumatic conveying system's operating pressure, but there are two situations where density does affect the calculation.

- With equal air volumes: The second term of the equation calculates the material kinetic energy leaving the conveying system. If the materials being compared have identical feedrates, then system pressure should be identical — except if the velocity of the material leaving the system is different. Table II shows the test data comparisons.

- With minimum air volumes: When we compare the data obtained under minimum conveying velocity for the two materials, we get the results shown in Table III. Almost identical system pressures are required for the various conveying rates when both materials are conveyed at their minimum pickup velocity.

Another way of looking at the conveying of higher density material is that the system pressure is the same but the airflow must be increased, as shown in Table IV.

Conclusions and summary

Conclusions from the material density and dilute-phase pneumatic conveying system tests show:

- The minimum pickup velocity for these two ⅛-inch-diameter materials, with an 8-to-1 bulk density difference, requires an average 40.2 percent increase.
- For identical feedrate and airflow, conveying the lead pellets required on average 18.8 percent less pressure than conveying the polyethylene pellets.
- When conveying at the minimum pickup velocity for each material, the pressure required for either material was very similar, with only experimental differences recorded.

When designing a conveying system to handle more than one material and the bulk density of those materials is substantially different, the chosen pickup velocity must be high enough to convey the heavy material. If the system pressure is calculated for this heavy material, however, the pressure will be lower than that required to convey lighter materials. Both system pressures must be calculated to obtain sufficient air volume to handle the heavy material and sufficient pressure to handle the lighter material. **PBE**

Author's note: Very few pneumatic conveying systems are strictly horizontal. They typically include vertical sections of convey line routing. Zenz and Othmer equation 11.2 is basically the same as 11.1, but there's an additional term that accounts for the inventory of material being suspended and lifted by the gas in a vertical section of convey line.

References

1. Zenz, F.A. and Othmer, D.F., "Fluidization and Fluid-Particle Systems," Reinhold Publishing Corp., New York, 1960, pp. 313 – 374.

For further reading

Find more information on this topic in previous "Pneumatic points to ponder…" columns or in articles listed under "Pneumatic conveying" in *Powder and Bulk Engineering*'s article index in the December 2017 issue or the Article Archive at *PBE*'s website, www.powderbulk.com. (All articles and columns listed in the archive are available for free download to registered users.)

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