Pneumatic Conveying:

Design and Optimization Fundamentals

By David A. Renfert, P.E., and Richard D. Wiehe, P.E.

Designing or optimizing a pneumatic conveying system requires careful analysis of system requirements, material characteristics, and conveying velocity in order to obtain the best achievable conveying condition while minimizing energy requirements, product degradation and equipment costs.

The basic science behind pneumatic conveying involves supplying potential energy in the form of air pressure to create sufficient airflow in a pipe or tube to transport a flowable material to a destination. The potential energy is converted to kinetic energy of the gas / material mixture, which is used to overcome the friction of the material and air moving though the pipe, as well as to change the potential energy of the material by changing its elevation.

Pneumatic conveying systems operate within a range bounded by solid dense-phase conveying (high material-to-air ratios) and dilute-phase conveying (low material-to-air ratios). A two-phase region exists between the dense and dilute phases in which both types of flow patterns are observed.

Conveying streams operate in dense phase when the velocity in the open area of the pipe is below the saltation velocity of the material. Saltation velocity is defined as an inherent material characteristic that equals the actual gas velocity in a horizontal pipeline at which particles in a homogeneous mixture with the conveying gas begin to fall out of the gas / material stream.

As the conveying velocity increases, more material becomes entrained in the air stream and the free area of the pipe increases in size until the air velocity profile across the entire pipe diameter reaches the saltation velocity. At this point, the system is operating in dilute phase.

The main factors in pneumatic conveying are material capacity, air volume (velocity) and system pressure. Studying the relationship between these factors shows how changing one factor will change one or both of the other factors.

Looking at the energy equation between two points along a pipe: potential energy at point 1 (PE_1) plus the kinetic energy at point 1 (KE_1) plus the work done from point 1 to point 2 ($Work_{1\rightarrow 2}$) equals the potential energy at point 2 (PE_2) plus the kinetic energy at point 2 (KE_2).

$$PE_1 + KE_1 + Work_{1\rightarrow 2} = PE_2 + KE_2$$

(Equation 1)

The potential energy terms in Equation 1 are changes in elevation (ΔPE_{elev}) and pressure ($\Delta p_{1\rightarrow 2}$) in the system. The work term is the energy required to overcome the frictional losses in the system, which includes the friction between the material and pipe wall ($W_{f,solids/pipe}$), the friction between the gas and pipe wall ($W_{f,gas/pipe}$) and the friction between the solid and gas ($W_{f,solids/gas}$). The kinetic energy terms consist of the changes in the kinetic energy of the solids (ΔKE_{solids}) and the gas (ΔKE_{gas}). By

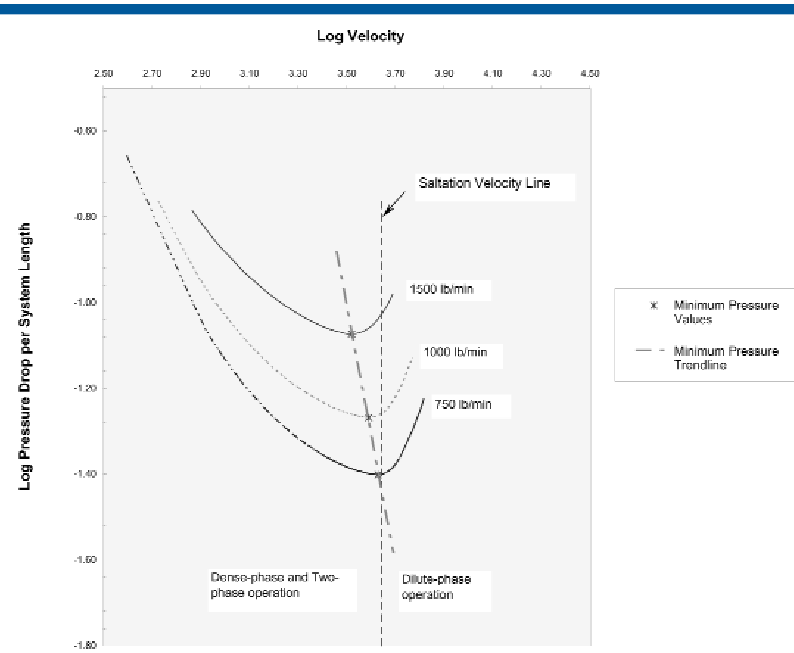

Figure 1
System Pressure Drop per Length vs. Velocity

substituting these terms into Equation 1 and rearranging terms, the following equation is developed:

$$\Delta p_{1\rightarrow 2} = \Delta PE_{elev} + \Delta KE_{solids} + \Delta KE_{gas} - (W_{f,solids/pipe} + W_{f,solids/air} + W_{f,air/pipe})$$

(Equation 2)

Figure 1: System Pressure Drop per Length vs. Velocity indicates the general effect that changing conveying velocity has on system pressure when the system capacity, pipe diameter and system geometry are held constant. Each curve represents a different capacity, and the "U" shape of a plot line is representative of any pneumatic conveying system.

The shape of the curve is due to the changing influence of each energy loss term as the material-to-air ratio decreases and the conveying velocity increases. The leftmost part of the curve represents a system operating in solid dense-phase conveying where the system kinetic energy and the air friction losses are small. On this part of the curve, the work to overcome the friction between the material and the pipe is the prevalent term.

As more air is introduced into the system, the material begins to fluidize and behave more like a liquid. As a result, the energy required to overcome the friction between the material and the pipe decreases and the system pressure drop decreases. Further addition of air continues to lower system pressure drop until minimum system pressure drop is reached. At this point the reduction of the material-to-pipe friction is equal to the increases in the system kinetic energy and the air-to-pipe friction terms.

As the minimum pressure point is approached (left to right on Figure 1), the flow transitions into the two-phase flow region where part of the material transfer occurs in a dilute-phase layer at the top of the pipe. At the minimum pressure point the system is operating in the two-phase flow regime. At this point the cross-sectional flow pattern consists of dilute-phase conveying occurring in the top of the pipe and a fluidized bed traveling along the bottom.

The introduction of more air into the system will continue to increase the dilute-phase layer until the dense-phase layer at the bottom of the pipe disappears. At this point of operation, the velocity profile across the entire pipe diameter is above the saltation velocity. The kinetic energy, air-to-pipe friction and material-to-air friction terms will continue to become more prevalent in the energy equation and the material-to-pipe friction loss will be minimized. As a result, additional pressure is required to move the same amount of material. This aspect of the system can be seen on the right side of Figure 1.

Although many factors affect design and performance of a pneumatic conveying system, an understanding of the relationship between pressure drop and velocity is key in optimizing and troubleshooting pneumatic conveying systems.

David A. Renfert *is a mechanical engineer in Burns & McDonnell's Nofsinger process division. He has a bachelor's degree in mechanical engineering from the University of Missouri-Rolla.*

Richard D. Wiehe *is an associate mechanical engineer in Burns & McDonnell's Nofsinger process division. He has bachelor's degrees in agricultural and mechanical engineering from the University of Missouri-Columbia.*