A Quick Check Method For The Design Of Pneumatic Conveying Systems

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INTRODUCTION

The design of pneumatic conveying systems is usually carried out on the basis of scaling data obtained from the pneumatic conveying of the material to be transported. If previous experience of conveying a given material is not available, data is generally derived for the purpose by conveying the material through a test facility. Most manufacturers of pneumatic conveying systems have such test facilities for this purpose.

If it is required to make a quick check on the potential of an existing system, or to provide a check on design proposals, there is little information readily available for the engineer to use. Pneumatic conveying does not lend itself to simple mathematical analysis, and it is likely that many engineers would not be able to undertake such a task easily, particularly if it were a low velocity dense phase system.

Since pneumatic conveying systems tend to have high power ratings, particularly for conveying in dilute phase suspension flow, it is useful to be able to obtain a rough estimate of air requirements at the feasibility stage of a project. Most of the operating cost of a pneumatic conveying system is in the drive for the air mover. If an estimate can be made of the system air requirements, it is a simple matter to evaluate the operating cost in cents per ton conveyed to see if it is at an acceptable level before proceeding further.

In this paper a straightforward method is presented which will allow a check to be made on the design of a pneumatic conveying system in a very short space of time, whether for a new or an existing system. Horizontal and vertical sections of pipeline and bends are all accommodated, as well as dilute and dense phase conveying. For high-pressure systems the influence of stepped pipelines can also be incorporated.

The Design Process

The pressure required to convey a material through a pipeline can be divided into a number of component parts. The most important are the straight pipeline sections and the bends. For each of these elements there are a multitude of sub variables that can have an influence, but their incorporation necessarily adds to the complication of the process. A compromise is clearly needed in order to provide a Quick Check Method.

Straight Pipeline

A considerable amount of published data exists on the pneumatic conveying of materials through pipelines. Much of it was generated by the author when commissioned by the Department of Industry in the UK to write a Design Guide for Pneumatic Conveying (Ref 1). Typical data for the horizontal conveying of material through straight pipeline is presented in Figure 1.

Figure 1 is a graph of material flow rate plotted against air flow rate, which is the usual form for presenting conveying characteristics for materials. In this case the family of curves that are drawn are lines of constant pressure gradient in lbf/sq. in. per 100 ft of pipeline. The data was initially derived from conveying trials with barytes and cement (Ref 1), but has since been found to be reasonably close to that for many other materials.

Lines of constant solids loading ratio can be drawn quite easily on this plot as they are simply straight lines through the origin. Solids loading ratio is the dimensionless ratio of the mass flow rate of the material conveyed to the mass flow rate of the air used. For powdered and granular materials values below about 15 generally relate to high velocity dilute phase conveying, and values above about 50 indicate that a material is capable of being conveyed at low velocity in dense phase.

The data in Figure 1 represents the pressure gradient for conveying material through straight horizontal pipeline of 2 inch bore. As will be seen, it covers both dilute and dense phase, with a smooth transition between the two. This Quick Check Method is based on the use of this data and so it will be seen that there is no specific reference to material type. It must be recognized, therefore, that this is strictly a first approximate method only.

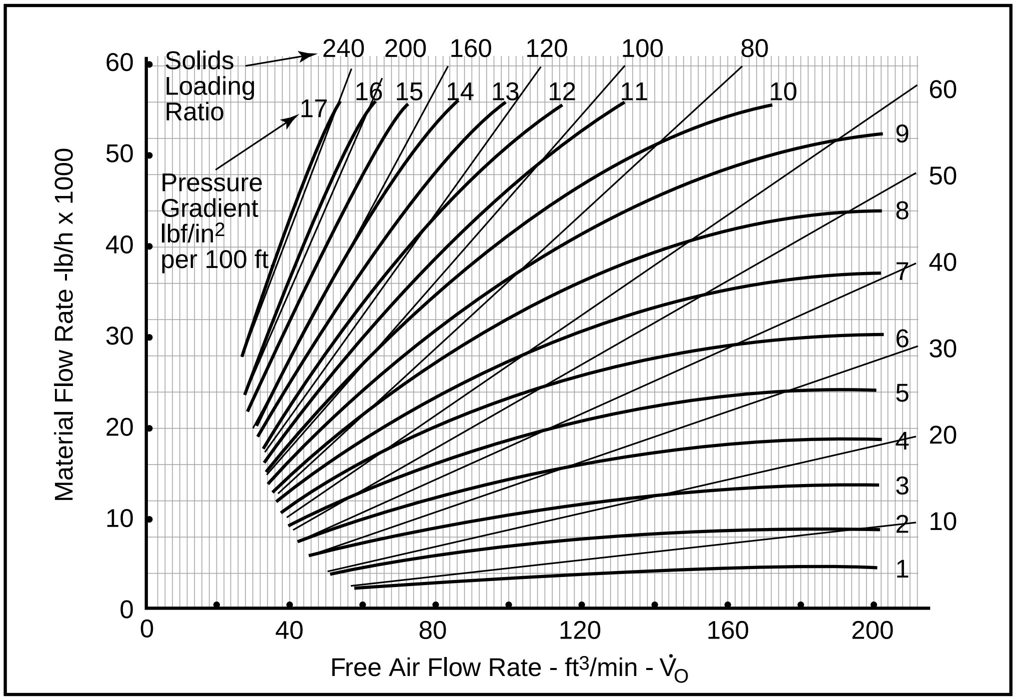


Figure 1: Pressure Gradient Data for Horizontal Conveying in 2 inch Bore Pipeline

To the pressure drop for conveying the material must be added the pressure drop for the air, and this will be considered later, as will the relationships between volumetric and mass flow rates for air. The effect of pipeline bore must also be considered, and this, of course, is also related to air flow rate. Straight vertical pipeline sections are another element that need to be taken into account, but these can conveniently be incorporated with Figure 1, as will be seen. Pipeline bends are a completely separate issue and will be dealt with later.

Vertical Pipelines

For flow vertically up, the author has found that the pressure gradient is approximately double that for horizontal conveying, and that this applies over an extremely wide range of solids loading ratios (Ref 1). To take account of vertically up sections of pipeline, therefore, the pressure gradient values on Figure 1 simply need to be doubled for any operating point on the chart.

For flows in vertically down sections of pipeline the situation is very different. In dense phase flows there is a pressure recovery, such that the pressure gradient has a negative value. For dilute phase flows, however, there is a pressure loss. The transition between the two occurs at a solids loading ratio of about 35 and at this value materials can be conveyed vertically down with no pressure drop at all (Ref 1). Figure 1, therefore, cannot be used in this case.

If, in a long pipeline, there is only a short length of vertically down pipeline, it is suggested that it can be ignored, in terms of the overall accuracy of the method. If a conveying system does have a significant proportion of pipeline that is vertically down, the user is referred to Reference 1.

Pipeline Bore

Material flow rate varies approximately in proportion to pipe section area, and hence in terms of (diameter)^2. Airflow rate, to maintain the same velocity in a pipeline of different bore, varies in exactly the same way. To determine the pressure gradient for flow in a pipeline having a bore different from that of the reference data in Figure 1, both the material and air flow rates should be adjusted in proportion to $(d_2/2)^2$, where d2 is the diameter of the plant pipeline in inches. It will be noted, therefore, that there will be no change in the value of the solids loading ratio.

It must be appreciated that along the length of a pipeline, as the pressure drops and the conveying air velocity increases, the pressure gradient is likely to increase. In Figure 1 a single value is given for the entire pipeline. This value can be taken to be an average for the pipeline, but it is another feature that reinforces the point that this is only an approximate method.

Stepped Pipelines

When high pressure air is employed it is usual to increase the bore of the pipeline to a larger diameter along the length of the pipeline (Ref 1). By this means the very high velocities that will result towards the end of a single bore pipeline, from the expansion of the air, can be prevented. By this means it is often possible to gain a significant increase in performance of the pipeline.

The pressure drop in a stepped pipeline can be evaluated in exactly the same way as outlined above. A critical point in stepped bore pipelines is the location of the steps along the length of the pipeline. At each step in the pipeline the conveying air velocity must not be allowed to fall below a given minimum value. The solution, therefore, will be an iterative one since the velocity of the air at the step depends upon the pressure at the step.

Pipeline Bends

Pressure drop data for bends in pipelines is presented in Figure 2. This is an identical plot to that in Figure 1 and covers exactly the same range of conveying conditions. The pressure drop in this case is for an individual bend in the pipeline and hence is in lbf/in^2 per bend.

for all bends, since 90° bends are likely to be in the majority in any pipeline. In the absence of any reliable data on the influence of pipeline bore it is suggested that the data in Figure 2 is used for all bends, regardless of pipeline bore. For larger bore pipelines the material and air flow rates will have to be scaled in the same way as outlined for the straight pipeline in Figure 1.

Air Only Pressure Drop

As mentioned earlier, the data in Figure 1 relates only to the conveying of the material through the pipeline, and so the pressure drop required for the air alone must be added. In Figure 3 the influence of pipeline bore on this pressure drop for a 500-ft. long pipeline is presented to illustrate the potential influence of the variables.

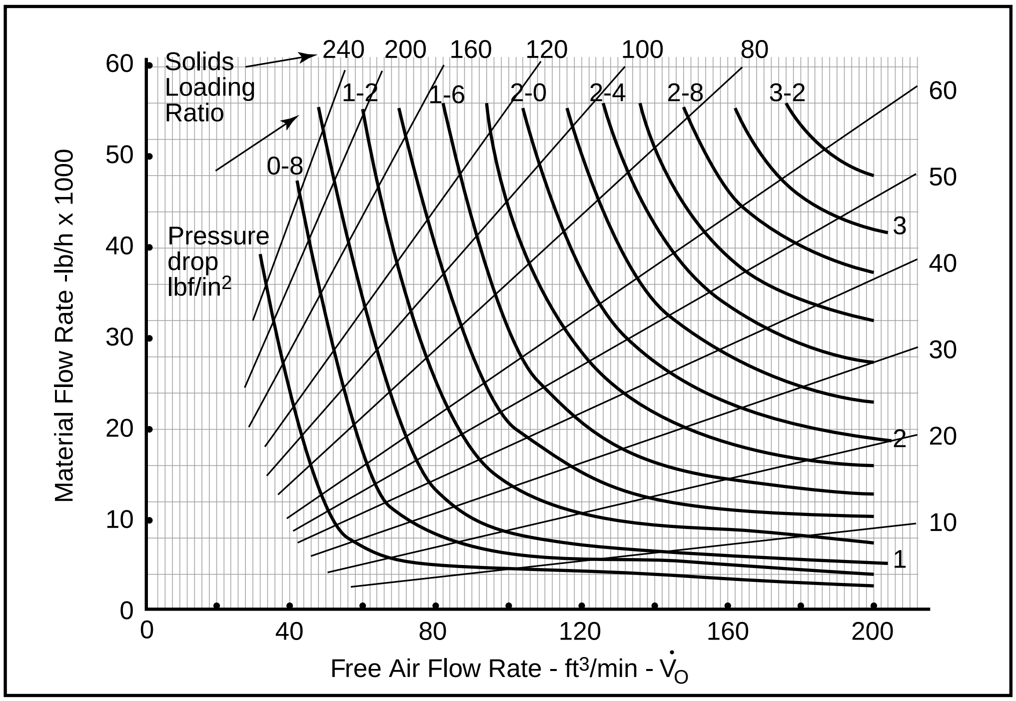


Figure 2: Pressure Drop Data for 90° Radiused Bends in 2-inch Bore Pipeline

The data given in Figure 2 relates to 90° radiused bends in a 2-inch bore pipeline. This is also data that was derived from conveying trials with barytes and cement (Ref 1), which has since been found to be reasonably close to that for other materials. From an extensive program of conveying trials with bends of different bend diameter, D, to pipe bore, d, ratios it was found that pressure drop varied little over a range of D/d ratios from about 5 to 30 (Ref 1). It has been found that the pressure drop in very sharp bends, and particularly blind tee bends, however, is significantly higher (Ref 1) and so an appropriate allowance should be made if any such bend has to be used, or is found to be fitted into a pipeline.

Little data exists for bends other than those having an angle of 90° and so it is suggested that the data in Figure 2 is used

Figure 3 shows the influence of air flow rate and pipeline bore on conveying line pressure drop for a representative pipeline length of 500 ft. It will be seen that conveying line exit air velocity has been added to the horizontal axis for reference. Conveying line inlet air velocity is the critical design parameter, but this cannot be added conveniently because it is also a function of the conveying line inlet air pressure. Because a range of pipeline bores are represented on this plot the air flow rate is in terms of that for the reference 2-inch bore pipeline $(d_2/2)^2$

From Figure 3 it will be seen that the air only pressure drop can be quite significant for long small bore pipelines. As there are many variables in this pressure drop relation-

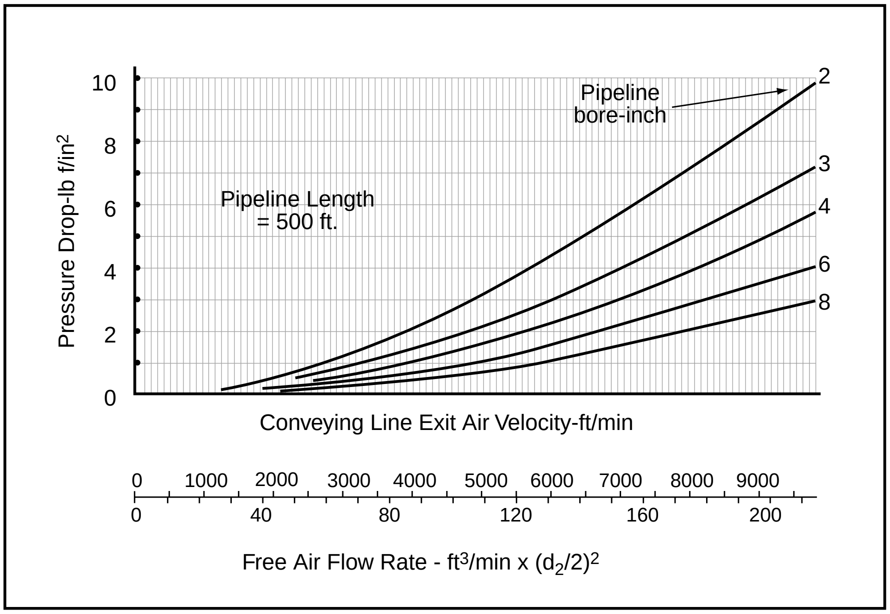


Figure 3: Influence of Pipeline Bore and Air Flow Rate on the Empty Pipeline Pressure Drop

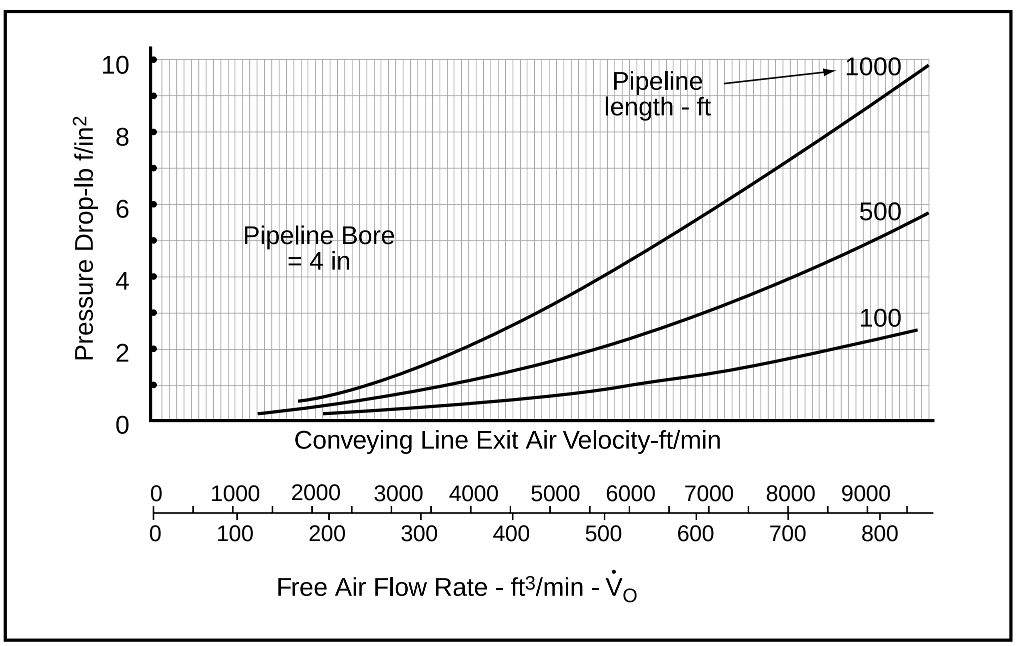
ship it is probably best to evaluate the pressure drop mathematically on an individual basis. Darcy's Equation can conveniently be used for this purpose:

$$\Delta p_a = \frac{4\ f\ L}{43{,}200\ d} \times \frac{\rho\, C^2}{2 g_c} \quad \text{lbf/in}^2 \quad --- (1)$$

where:

Δp_a = air only pressure drop - lbf/in²
f = friction coefficient - -
L = pipeline length - ft
d = pipeline bore - in
• = air density - lb/ft³
C = air velocity - ft/min
and g_c = gravitational constant
= 32 • 2 ft lb/lbf s²

For most cases a friction coefficient, f, can be taken as 0 • 005. Mean values of both air density and velocity should be used, but for quickness, since these two parameters will



initially be unknown, conveying line exit values can be taken. For air at standard atmospheric pressure • = 0 • 0765 lb/ft3 and the velocity can either be obtained from Figure 3 or be calculated.

Another graph, plotted for a 4-inch bore pipeline, is presented in Figure 4 to further illustrate the influence of pipeline length.

Air Flow Rate

The air flow rate to be specified for a blower or compressor is generally expressed in volumetric terms and specifically in terms of 'free air conditions.' Air is compressible with respect to both pressure and temperature, and this is why it has not been possible to represent conveying line inlet air velocities on Figures 3 and 4.

Conveying Air Velocity

Conveying air velocity, C, is derived by dividing the volumetric flow rate, $\dot{V}$, by the pipe section area:

$$C = \frac{576\ \dot{V}}{\pi\ d^2} \quad \text{ft/min} \quad - - - - \quad (2)$$

where:

C = conveying air velocity - ft/min
$\dot{V}$ = volumetric flow rate - ft^3/min
and d = pipeline bore - in

Ideal Gas Law

To take account of compressibility on volumetric flow rate, and hence conveying air velocity, Equation 2 is used in conjunction with the Ideal Gas Law:

$$144\ p\ \dot{V} = \dot{m}_a\ R\ T \quad - - - - - - \quad (3)$$

where:

p = absolute air pressure - lbf/in^2
= gauge pressure + 14 • 7
$\dot{V}$ = actual volumetric air flow rate at the pressure, p - ft^3/min
$\dot{m}_a$ = air mass flow rate - lb/min
R = characteristics gas constant
= 53 • 3 ft lbf/lb R for air
and T = absolute air temperature - R

Since both $\dot{m}_a$ and R will be constant, the usual working form of this equation is:

$$\frac{p\ \dot{V}}{T} = \text{constant} \quad - - - - - - - \quad (4)$$

This is then used either to equate points along a pipeline:

$$\frac{p_1\ \dot{V}_1}{T_1} = \frac{p_2\ \dot{V}_2}{T_2} \quad - - - - - - - - \quad (5)$$

where subscripts $_1$ and $_2$ can relate to any two points anywhere along the conveying pipeline.

Or to relate a chosen point with free air or reference conditions:

$$\frac{p_1\ \dot{V}_1}{T_1} = \frac{p_0\ \dot{V}_0}{T_0} \quad - - - - - - - - \quad (6)$$

where:

subscript o refers to reference conditions:
usually p_o = 14 •7 lbf/in^2 absolute
T_o = 519 R
= t°F + 460
and $\dot{V}_o$ = free air delivered in ft^3/min
and subscript $_1$ refers to actual conditions anywhere along the pipeline, but usually conveying line inlet (material feed or pick-up point).

Pick-Up Velocity

The velocity at the pipeline inlet, C_1, or pick-up velocity can be determined by combining Equations 2 and 6 to give:

$$C_1 = \frac{576\ T_1\ p_o\ \dot{V}_o}{\pi\ d^2\ p_1\ T_o} \quad \text{ft/min} \quad - - - \quad (7)$$

Substituting values for p_o and T_o in Equation 7 gives:

$$C_1 = 5 \cdot 119 \frac{T_1\ \dot{V}_o}{d^2\ p_1} \quad \text{ft/min} \quad - - - \quad (8)$$

where:

T_1 = air supply temperature - R
$\dot{V}_o$ = free air flow rate - ft^3/min
d = pipeline bore - in
and p_1 = air supply pressure - lbf/in^2 abs

Power Required

A first approximation model for compressor drive motor power required, P, in terms of free air flow rate, is (Ref 1):

$$P = 0 \cdot 128\ \dot{V}_o\ \ln\left(\frac{p_2}{p_1}\right) \quad \text{hp} \quad - - - \quad (9)$$

where:

$\dot{V}_o$ = free air flow rate - ft^3/min
p_1 = comp inlet pressure - lbf/in^2 abs
and p_2 = comp delivery pressure - lbf/in^2 abs

Material Capability

It must be emphasised that the potential for dense phase conveying of materials is strictly limited. Although the design method will cater for materials conveyed at solids loading ratios of up to 200 or more, as will be seen from Figures 1 and 2, it is the properties of the materials that dictate whether the material has the capability of being conveyed in dense phase, and hence at high solids loading ratios and with low conveying air velocities. It must also be recognised that the use of high pressure for conveying is not synonymous with dense phase conveying either.

Modes of Conveying

For continuous conveying, and batch conveying if the batch size is large, two modes of conveying are recognized. If the material is conveyed in suspension in the air through the pipeline, at high velocity, it is referred to as dilute phase conveying. If the material is conveyed at low velocity in a non-suspension mode, through all or part of the pipeline, it is referred to as dense phase conveying. Almost any material can be conveyed in dilute phase, suspension flow through a pipeline, regardless of the particle shape, size or density.

Dense Phase

In dense phase conveying two modes of flow are recognized. One is moving bed flow in which, in horizontal lines, the material is conveyed in dunes on the bottom of the pipeline, or as a pulsatile moving bed. The other mode is slug or plug type flow, in which the material is conveyed as full bore plugs separated by air gaps. Moving bed flow is only possible in a conventional conveying system if the material to be conveyed has good air retention characteristics. Plug type flow is only possible in a conventional conveying system if the material has good permeability.

Material Classification

A classification of materials in terms of conveying capability has been presented (Ref 2) and is shown here in Figure 5. This is a chart with material de-aeration rate plotted against permeability. For convenience the de-aeration rate was determined by vibrating the material from an 'as poured' condition rather than measuring it from a fluidized state (Ref 1). On the basis of these two material properties this chart will allow the conveying capability of a material to be assessed.

Materials that have very good air retention, and hence a low vibrated de-aeration rate value, such as cement and fine fly ash, fall into the Group 1 category, and will convey very well in a conventional conveying system. A simple test to apply is to half fill a glass jar, preferably having a screw top lid, with a sample of the material to be conveyed. Invert the jar a few times to aerate the material, place it on a surface, remove the lid, and drop a ball bearing or similar object into the jar.

If the ball bearing falls through the material and hits the bottom of the jar, the material is likely to have good air retention. With a material such as cement, the ball bearing will hit the bottom of the jar even if it is dropped in the jar several minutes after the material has been aerated and left standing, as it has such good air retention properties. If the material is granular, or has a very wide particle size distribution, the ball bearing is unlikely to penetrate the material and will simply come to rest on the top surface.

In this case the material is unlikely to have sufficient air retention to allow it to be conveyed in dense phase in a conventional conveying system. If the material has good permeability, however, such that it falls into Group 3, it is possible that the material will convey at low velocity in the plug type dense phase mode of flow. Pelletized materials, such as polyethylene and nylon, are ideal candidates and will convey very well in a conventional conveying system.

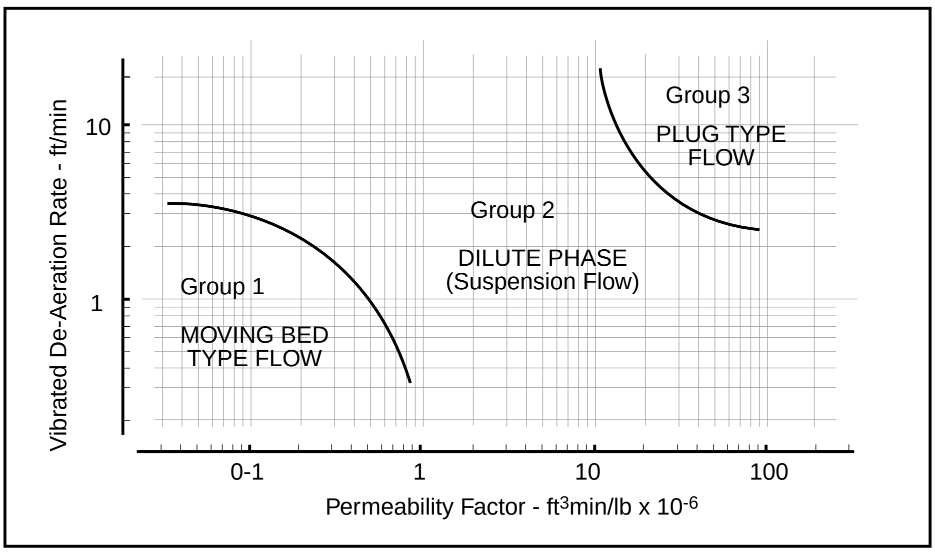


Figure 5: Material Classification for Pneumatic Conveying

It should be noted that this Quick Check Method does not hold for Group 3 materials conveyed in dense phase. These, and similar materials that have a marked pressure minimum point at the transition from dilute to dense phase conveying, such as pvc resin powder and terephthalic acid, have conveying characteristics that are markedly different from those of the Group 1 materials, and materials conveyed in dilute phase. The accuracy of the method starts to reduce below the pressure minimum point and so cannot be recommended for the low velocity conveying of this type of material.

Conveying Characteristics

In order to illustrate these various differences in material conveying capability, a number of conveying characteristics are included. Data on four different materials is presented, and in each case the material was conveyed though a 165-ft.-long pipeline of 2-inch nominal bore having about nine 90° bends (Ref 1).

The conveying characteristics in Figure 6 are those for Ordinary Portland Cement. This material could be conveyed quite naturally in dense phase, and with a conveying line pressure drop of 20 lbf/in^2 conveying could be achieved with only 40 ft^3/min of free air, giving a conveying line inlet air velocity of about 700 ft/min. Cement, therefore, is a Group 1 material that will convey at low velocity and high solids loading ratio in dense phase in a moving bed type of flow in a conventional pneumatic conveying system.

The conveying characteristics in Figure 7 are those for granulated sugar. As will be seen, this material has no dense phase conveying capability at all, regardless of the fact that high pressure air was available for conveying. With a conveying line pressure drop of 20 lbf/in^2 more than 160 ft^3/min was required, and this corresponds to a conveying line inlet air velocity of about 3000 ft/min, which is more than four times that required by the cement.

These two sets of conveying characteristics are shown together, and plotted to the same axes, so that the differences between dilute and dense phase conveying can be highlighted. The major difference between the two will be seen with the location of the conveying limits and the extent of the ‘no go areas’. Most designs for the pneumatic conveying of cement would be at air and material flow rates that could not possibly be achieved with sugar. This, of course, poses problems should a system designed for one material be required to convey another material, or even a different grade of the same material (Ref 1).

Conveying performances are compared in Table 1 for a conveying line pressure drop of 20 lbf/in^2.

Similar data for the pneumatic conveying of polyethylene pellets and pvc resin is presented in Figures 8 and 9. Both of these materials show distinct pressure minimum points.

The polyethylene pellets are typical of Group 3 materials. Solids loading ratios are relatively low as a result of the very high permeability of the material, but the material can be conveyed successfully with low air flow rates, and hence with low values of conveying line inlet air velocity. A marked maximum value of material flow rate, at a given value of conveying line pressure drop occurs, however, and this would appear to correspond with the transition from dilute to dense phase conveying, which corresponds approximately to a conveying line inlet air velocity of 2800 ft/min. The pvc resin shown in Figure 9 is clearly a Group 1 material, having good air retention and poor permeability, and capable of being conveyed in dense phase at high values of

Figure 6: Cement

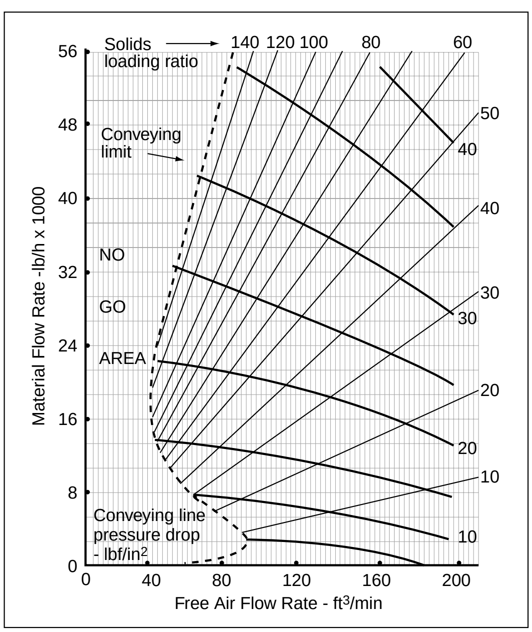
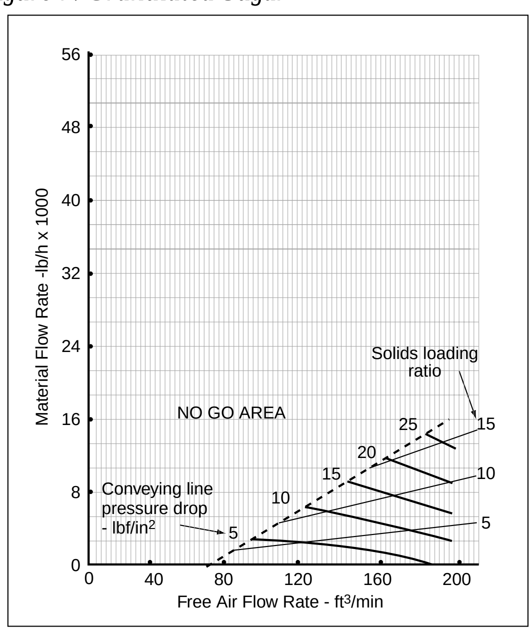


Figure 7: Granulated Sugar



Figures 6 and 7: Conveying Characteristics of Typical Group 1 and 2 Materials

Table 1: Comparison of Conveying Performance for Cement and Sugar

CONVEYING PARAMETER	CEMENT	SUGAR
Minimum air flow rate - ft^3	40	160
Maximum material flow rate - lb/h	22,000	11,000
Maximum solids loading ratio	120	15
Minimum conveying air velocity - ft/min	700	3000

Figure 8: Polyethylene Pellets

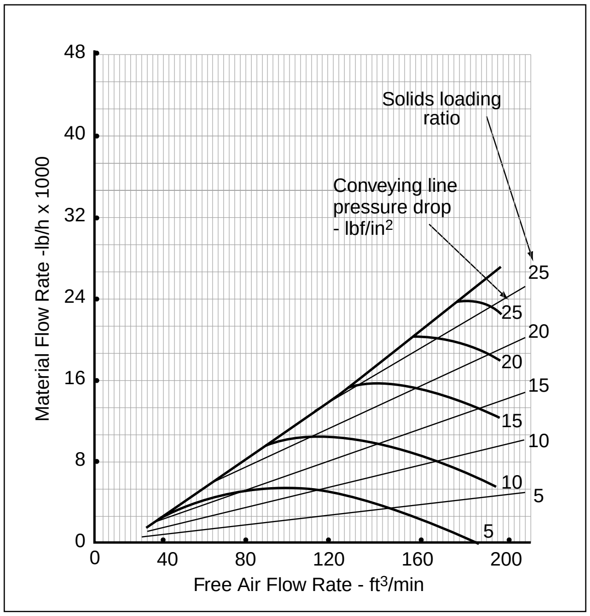


Figure 9: pvc Resin

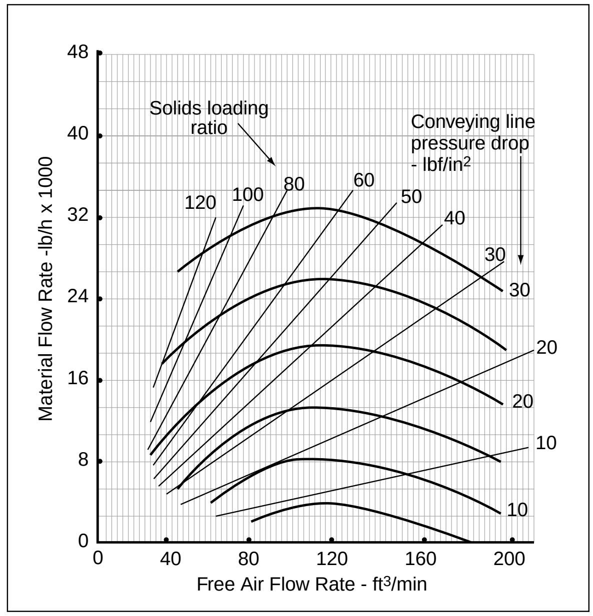


Figure 8 and 9: Conveying Data for Materials that have Pressure Minimum Characteristics

solids loading ratio and at low velocity. This material also displays a marked pressure minimum point, however, with a change to a reduction in material flow rate with further reduction in air flow rate. The accuracy of this Quick Check Method, as mentioned earlier, starts to reduce below the pressure minimum point and so cannot be recommended for the low velocity conveying of this type of material.

Minimum Conveying Air Velocity

For dilute phase conveying a relatively high conveying air velocity must be maintained, to ensure that the material does not drop out of suspension and block the pipeline. This is typically in the region of 2000 to 2400 ft/min for a very fine powder, to 2800 to 3200 ft/min for a fine granular material, and beyond for larger particles and higher density materials. For dense phase conveying, air velocities can be down to 700 ft/min, and lower in certain circumstances, and this applies to both moving bed and plug type dense phase flows.

Pick-Up Velocity

It is generally recommended that, for design purposes, the pick-up, or conveying line inlet air velocity at the material feed point, should be about 20% greater that the minimum conveying air velocity. This should provide sufficient margin to allow for surges in material flow, air mover characteristics, and other contingencies. An unnecessarily high conveying air velocity should not be employed as this will have an adverse effect on system performance, in terms of air pressure needed, and hence power requirements, as will be seen from the design charts provided.

For guidance purposes an approximate value of the pick-up conveying air velocity to be employed for pneumatic conveying is given in Figure 10. For convenience, materials here are classified as being either floury or sandy. Floury materials are those that are very fine, have very good air retention properties, and will convey in dense phase in a moving bed type of flow. Sandy materials are typically fine granular materials that have neither air retention nor permeability, and so will only convey in dilute phase suspension flow.

For a typical sandy material, a pick-up velocity of about

3500 ft/min has been taken, and this will remain approximately constant, regardless of solids loading ratio and air supply pressure. For a typical floury material, however, the pick-up velocity, C_{in}, will depend upon the solids loading ratio, ϕ, at which the material is conveyed. This is defined approximately by:

$C_{in} = 2500$ for $\phi < 100$ - - - (10)

$C_{in} = 8860\ \phi^{-0.55}$ for $10 < \phi < 100$

$C_{in} = 700$ for $\phi > 100$ - - - (10)

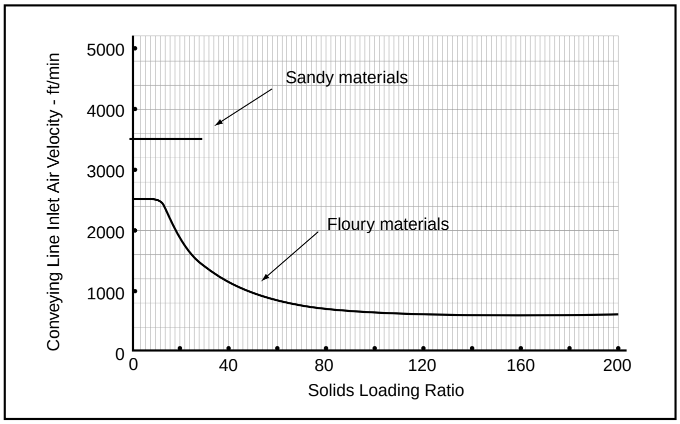


Figure 10: The Influence of Solids Loading Ratio on Conveying Line Inlet Air Velocity for Sandy and Floury Materials

Evaluation

It must be stressed that the effects of compressibility of the air must be taken into account when evaluating the conveying line inlet air velocity. This means that both the pressure and temperature of the air at the material pick-up point must be included in the calculation, along with pipeline bore, in order to convert the volumetric air flow rate, specified as being available for conveying, into an air velocity.

This is because the rating of the air mover, in volumetric terms, will almost certainly be based on a different pressure and temperature than that prevailing at the pipeline inlet. An appropriate equation (8) was developed earlier in the paper.

Solids Loading Ratio

The solids loading ratio, _, at which the material is conveyed is a useful parameter in helping to visualise the flow. It is the dimensionless ratio of the material to air flow rates, so that:

$$\phi = \frac{\dot{m}_p}{\dot{m}_a} \qquad - - - - - - - - \quad (11)$$

where $\dot{m}_p$ = material flow rate - lb/h

and $\dot{m}_a$ = air flow rate - lb/h

Air flow rate is generally specified in volumetric terms at free air conditions and so this value, in ft^3/min, needs to be converted to a mass flow rate in lb/h.

Air density can be evaluated from Equation 3, and if values for R and free air conditions are substituted it will be found that the air density at free air conditions is 0·0765 lb/ft^3. Air mass flow rate in lb/h is then given by:

$$\dot{m}_a = 0 \cdot 0765 \cdot \dot{V}_o \cdot 60$$

so that:

$$\phi = \frac{\dot{m}_p}{4 \cdot 59\ \dot{V}_o} \qquad - - - - - - - - \quad (12)$$

Where ϕ = solids loading ratio

$\dot{m}_p$ = material flow rate - lb/h

and $\dot{V}_o$ = free air flow rate - ft^3/min

For dilute phase conveying, maximum values that can be achieved are typically of the order of 15, although this can be higher if the conveying distance is short. For moving bed flows, solids loading ratios of well over 100 can be achieved if materials are conveyed with pressure gradients of the order of 12 lbf/in^2 per 100 ft of pipeline.

Influence of Distance and Pressure

The design method presented here is an iterative process, and particularly so for dense phase conveying where the conveying line inlet air velocity is a function of the solids loading ratio. To provide some guidance in this process, for dense phase conveying, the potential influence of conveying distance and air supply pressure on the solids loading ratio is presented in Figures 11 and 12 (Ref 1). Once again it must be stressed that these figures are only approximations for the purpose of illustration and should on no account not be used on their own for design purposes.

Figure 12 is drawn for high pressure, long distance conveying systems, with air supply pressures up to 60 lbf/in^2 gauge and pipeline lengths of up to 2500 ft. Figure 11 is drawn for shorter distance, low pressure systems, up to 15 lbf/in^2 gauge, with vacuum conveying to 10 lbf/in^2 included, and pipeline lengths of up to 500 ft.

It should be noted that dense phase conveying is possible with low pressure vacuum conveying systems, as will be seen on Figure 11. This is because dense phase conveying is a function of pressure gradient, for an air retentive material, as mentioned above, and does not depend on distance or pressure drop alone.

Figures 11 and 12 are included in order to provide guidance in the design process presented. Pipeline bore, conveying air velocity, and material type, will all have an influence on the overall relationship and so they can not be used for design purposes alone, as mentioned earlier.

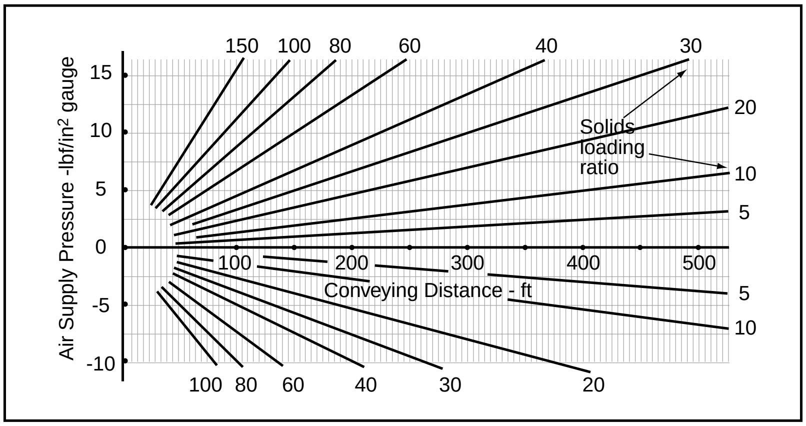


Figure 11: The Influence of Air Supply Pressure and Conveying Distance on Solids Loading Ratio on Solids Loading Ratio for Low Pressure Pneumatic Conveying Systems

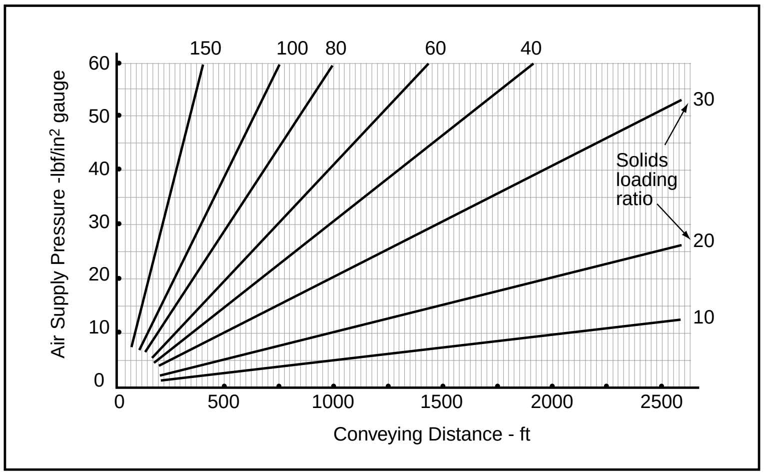


Figure 12: The Influence of Air Supply Pressure and Conveying Distance on Solids Loading Ratio for High Pressure Pneumatic Conveying Systems

THE DESIGN PROCEDURE

To illustrate the design and checking procedure a case study is presented below.

Dilute Phase Conveying

It is proposed to investigate the possibility of conveying a sandy material at a flow rate, $\dot{m}_{p1}$, of 80,000 lb/h using a positive displacement blower and a positive pressure conveying system. The pipeline is 300 ft long, with 250 ft of this horizontal and 50 ft of vertical lift, giving an equivalent length, L, of 350 ft, with five 90° bends in addition. It is assumed that the temperature of the air and material at the conveying line inlet, T_1, are 530 R (70°F). In the first instance the possibility of conveying the material in an 8-inch bore pipeline, d_1, will be investigated.

Since the material can only be conveyed in dilute phase suspension flow a conveying line inlet air velocity, C_1, of 3500 ft/min has been taken, as indicated on Figure 10. With a Roots type blower the pressure will typically be limited to 15 lbf/in² gauge and so to get the process started a conveying line inlet air pressure, p_1, of 24 · 7 lbf/in² absolute (10 lbf/in² gauge) is assumed.

The equivalent mass flow rate of material, $\dot{m}_{p2}$, in a 2-inch bore pipeline, d_2, can be determined by using the

$$\dot{m}_{p2} = \dot{m}_{p1} \times \left[\frac{d_2}{d_1}\right]^2 \text{ lb/h} \quad - - - (13)$$

$$= 80{,}000 \times \left[\frac{2}{8}\right]^2$$

$$= 5000 \text{ lb/h}$$

square law relation-ship on pipeline bore presented earlier:

Two reference points are required for Figures 1 and 2. Material flow rate is one and either free air flow rate or solids loading ratio can be used for the other. Since a conveying line inlet air velocity and pipeline bore have both been selected, air flow rate is the more convenient to determine. By re-arranging Equation 8 an expression for free air

$$\dot{V}_o = \frac{C_1 \, d^2 \, p_1}{5 \cdot 19 \, T_1} \text{ ft}^3\text{/min} \quad - - \quad \mathbf{(14)}$$

Substituting values given in the above text:

$$\dot{V}_o = \frac{3500 \times 8^2 \times 24 \cdot 7}{5 \cdot 19 \times 530} = 2011 \quad ft^3/min$$

flow rate is obtained:

The equivalent free air flow rate in a 2-inch bore pipeline is determined in exactly the same way as for material flow rate in Equation 13, which gives 126 ft^3/min.

Using these two reference points on Figure 1 gives a pressure gradient of about 1·5 lbf/in^2 per 100 ft, and as the equivalent length of pipeline is 350 ft, this element of pressure drop will be about 5·25 lbf/in^2. Using these same two reference points on Figure 2 gives a pressure drop of 0·8 lbf/in^2 per bend and so for five bends this comes to about 4·0 lbf/in^2.

From Equation 1 the air only pressure drop for the pipeline is about 1·15 lbf/in^2. Thus the pressure drop required to convey the material at 80,000 lb/h through the 8-inch bore pipeline will be about 5·25 + 4·00 + 1·15 = 10·4 lbf/in^2. It will also be seen that the solids loading ratio is about 10. From Equation 9 the approximate power required can be determined, and substituting values gives 138 hp.

If the resulting pressure drop is too far from the initial estimate it would be recommended that the process be repeated with new data until a balance is achieved. Since a wide range of pipeline bore and air supply pressure combinations will be capable of achieving the duty, it is always worthwhile investigating a number of different options, as they are likely to lead to different system costs and operating power requirements (Ref 1).

Dense Phase Conveying

The procedure for dense phase conveying systems is essentially similar to that outlined above. It is a little more complicated, however, in that there is an additional iteration to be included because of the fact that the conveying line inlet air velocity is a function of the solids loading ratio, as shown on Figure 10, and this must be included in the checks and balances at the end of the procedure.

Conclusion

In conclusion it must be stated once again that there is no mention of material type in this analysis at all and so any results derived should only be used for comparative purposes and feasibility studies, and not directly for system design.

C	Conveying air velocity	- ft/min
d	Pipeline bore	- in
f	Pipeline friction coefficient	- -
g_c	Gravitational constant = 32 . 2 ft lb/lbf s^2	
L	Pipeline length	- ft
$\dot{m}_a$	Air mass flow rate	- lb/min or lb/h
$\dot{m}_p$	Material flow rate	- lb/h
p	Air pressure (absolute) = 14 . 7 + gauge pressure	- lbf/in^2
P	Power required	- hp
R	Characteristic gas constant = 53 . 3 ft lbf/lb R for air	
t	Actual air temperature	- °F
T	Air temperature (absolute) = t + 460	- R
$\dot{V}$	Volumetric flow rate of air	- ft^3/min

NOMENCLATURE

Greek

ρ	Air density	- lb/ft^3
ϕ	Solids loading ratio	- -

Prefixes

Δ	Difference in value

Subscripts

a	Air
p	Conveyed material or product
in	Conveying line inlet conditions
o	Free air or reference conditions:

$\dot{V}_o$ = Free air flow rate - ft^3/min

p_o = 14·7 lbf/in^2

T_o = 519 R

ρ_o = 0·0765 lb/ft^3

1 Inlet or supply air conditions

2 Exit or delivery air conditions or any two points along a pipeline or system reference numbers

References

1. *D Mills. Pneumatic Conveying Design Guide. Butterworth-Heinemann. 1990.*
2. *M G Jones and D Mills. Product Classification for Pneumatic Conveying. Powder Handling and Processing. Vol 2. No 2. June 1990.*