11

Pneumatic Conveying of Food and Chemicals

1 INTRODUCTION

A vast number of different materials are conveyed in both the food and chemicals industries. Probably as a consequence food and chemical products tend to have a reputation for causing more problems in both the design and operation of pneumatic conveying systems than any other group of materials. They can exhibit an extremely wide range of conveying capabilities; certainly wider than those of coal and ash considered in the previous chapter, and their conveying performance can also vary during conveying. As with most materials, there is a dilute to dense phase capability limitation, but with food and chemical products there is a more pronounced divide between moving bed and plug type flows, for those materials that are capable of being conveyed in dense phase.

These materials tend to come in a wide variety of forms, from fine powders to granules and pellets, and the conveying performance of each can differ widely. The name of a material alone, in most cases, is not sufficient to define its conveying capability, for the same material can come in a number of different forms and grades, and the performance of each can vary significantly. The main differences are in the minimum conveying air velocity necessary for conveying, and in the air supply pressure necessary to convey at a given rate. An adverse change in either one of these parameters is likely to result in pipeline blockage.
1.1 Systems and Components

In terms of the types of conveying systems employed for food and chemical products the entire range of systems considered in chapter 1 are used. Probably the majority of these materials in finely divided form are potentially explosive and many have very low values of minimum ignition level. As a consequence closed loop systems and the use of nitrogen for conveying is not uncommon.

The entire range of feeding devices considered in Chapter 2 are also employed, although high pressure rotary valves are often preferred to blow tanks for high pressure conveying systems. Blow tanks are widely used for coal and ash, considered in the previous chapter, and there are no reasons why they could not be more widely accepted in the food and chemicals industries. Other system components such as air movers, filters and valves are more or less common to all industries.

1.2 Erosion and Degradation

Erosive wear tends not to be a problem of major concern, as it is with coal and ash, although with many harvested grains and seeds it does need to be given due consideration. Attrition and degradation of many materials, however, is often a major concern. As a consequence data is presented for a number of representative materials, specifically to illustrate the effects that pneumatic conveying can have on this group of materials. The problems of material degradation are considered in more general terms in Chapter 21.

1.3 Conveying Data

To illustrate the nature of the problems of pneumatic conveying, and to show the range of conveying characteristics that can be obtained with different materials, performance data for a number of materials is presented. This conveying data will also help to show that virtually any food or chemical product can be conveyed in a pneumatic conveying system, although a large bore pipeline or a high air supply pressure may be required to achieve the desired flow rate with some materials.

2 LOW PRESSURE CONVEYING

Data is presented for a number of different materials conveyed through two different two inch nominal bore pipelines. Conveying characteristics for ammonium chloride and PVC resin powder conveyed through the Figure 10.16 pipeline are presented in Figures 11.1 and 11.2. In each case the materials were fed into the pipeline by means of a low pressure bottom discharge blow tank. A blow tank was used because this one device is capable of feeding a very wide range of materials over an extremely wide range of conveying conditions. A positive displacement blower was available, having a pressure capability of about 12 lbf/in² and volumetric flow rate of approximately 140 ft³/min at free air conditions.
Figure 11.1 Conveying characteristics for ammonium chloride conveyed through the pipeline shown in figure 10.16.

Sketches of the two pipelines were presented earlier in Figures 4.11 and 10.16. These provide details of pipeline lengths and the number and geometry of bends for reference.

Figure 11.2 Conveying characteristics for PVC resin powder conveyed through the pipeline shown in figure 10.16.
Figure 11.3 Conveying characteristics for sodium chloride (salt) conveyed through the pipeline shown in Figure 4.19.

Conveying characteristics for sodium chloride (salt), and a ‘heavy’ grade of soda ash (sodium carbonate), conveyed through the Figure 4.15 pipeline, are presented in Figures 11.3 and 11.4. These two pipelines referenced here have exactly the same pipe bore and are very similar in geometry. The Figure 4.15 pipeline is just 5 feet longer and has one more 90° bend than the Figure 10.16 pipeline.

Figure 11.4 Conveying characteristics for sodium carbonate (soda ash) conveyed through the pipeline shown in Figure 4.19.
2.1 Conveying Capability

Because of the relatively high pressure gradient required to convey a material in dense phase, as illustrated in Chapter 8, low pressure conveying is generally limited to dilute phase conveying, unless the conveying distance is very short, as will be seen from Figures 11.1 to 11.4. In dilute phase, however, almost any material can be pneumatically conveyed, regardless of the size, shape and density of the particles. With low air pressures, positive displacement blowers and conventional low pressure rotary valves can be used and simple systems can be built. As a result dilute phase is probably the most common form of pneumatic conveying for this group of materials.

A much higher conveying line inlet air velocity must be maintained for dilute phase systems, even if the material is capable of being conveyed in dense phase. Conveying line inlet air velocities are typically of the order of 2000 to 2400 ft/min for fine powders, 3000 to 3400 ft/min for granular materials, and beyond for larger particles and higher density materials, but provided that this minimum velocity is maintained, most materials can be reliably conveyed. Differences in conveying capability, however, must be expected for different materials, even when conveyed in dilute phase, suspension flow and this point is clearly illustrated with Figures 11.1 to 11.4.

Although a diverse group of materials is included in Figures 11.1 to 11.4, there is not a lot of difference in their conveying capabilities with respect to air requirements. Minimum values of conveying air velocity were about 2200 ft/min for the ammonium chloride and 2300 ft/min for the PVC resin, salt and soda ash. Much greater differences in material flow rates were achieved, however, but this is to be expected following the comparative data plots presented in Figures 4.18 and 4.18. Considering a conveying line pressure drop of 8 lbf/in², for example, a maximum material flow rate of about 10,000 lb/h could be achieved with the ammonium chloride in Figure 11.1. This reduces to 8,500 lb/h for the PVC resin in Figure 11.2, to 6,500 lb/h for the salt in Figure 11.3 and to only 5000 lb/h for the soda ash in Figure 11.4.

It will be noted that with the PVC resin there is a maximum value of material flow rate achieved for a given value of conveying line pressure drop. This does occur with certain materials and tends to be more marked in high pressure conveying, for materials that are capable of being conveyed in dense phase and hence at low velocity, as will be illustrated later in this chapter. This is often referred to as a pressure minimum point, for it also results in a minimum value of pressure drop for a given material flow rate.

The conveying capability of some of these materials is considered further when data on the high pressure conveying capability of materials is presented later in this chapter. For comparison, and reference purposes, a number of other materials conveyed through the Figure 10.18 pipeline are presented in Figures 10.17 to 10.19. Other materials conveyed through the Figure 4.15 pipeline are presented in Figures 4.14 and 4.16.
2.2 Material Degradation

With the sodium chloride and soda ash, presented in Figures 11.3 and 11.4 programs of conveying trials were undertaken to determine the level of degradation resulting from the pneumatic conveying of these materials [1]. Both materials were conveyed through the Figure 4.15 pipeline for this purpose. Fresh material was loaded into the test facility, it was circulated a total of five times and samples were taken during each run.

Guaranteeing uniformity and accuracy in the sampling of bulk particulate materials is always a problem and it is generally recommended that samples should be taken from a moving stream of the bulk material. In this case samples were taken by means of a diverter valve that was positioned near to the end of the pipeline.

For consistency an attempt was made to convey each material under similar conditions. It was not possible to employ identical conveying conditions for each material, of course, since the conveying characteristics differed, as will be seen from Figures 11.3 and 11.4. The approximate minimum and maximum values of conveying air velocity were 3400 and 4400 ft/min and the solids loading ratio was about five. A size analysis of all the samples obtained from the fresh material, and each of the five times the materials were re-circulated, was carried out and the results are presented in Figures 11.5 and 11.6.

Figure 11.5 Influence of conveying on the degradation of sodium chloride.

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In each case it will be seen that the material has degraded, and that a noticeable effect has been recorded every time each material was conveyed and recirculated. In Figure 11.7 mean particle size data for the two materials is presented so that a direct visual comparison can be made.

**Figure 11.6** Influence of conveying on the degradation of sodium carbonate.

**Figure 11.7** Influence of material conveying on mean particle size.
For the salt there was an overall reduction of about 78 μm from the fresh material, having a mean particle size of about 388 μm. For the soda ash there was an overall reduction of about 68 μm from the fresh material, having a mean particle size of about 343 μm.

3 HIGH PRESSURE CONVEYING

All of the preceding data in this chapter has been for the low pressure (up to 8 lbf/in²), and hence dilute phase, suspension flow of the materials considered, whether they had dense phase conveying capability or not. In this section, data is presented for materials conveyed with air pressures of up to 30 lbf/in² gauge.

With higher pressure air, for approximately the same length of pipeline, pressure gradients are now such that dense phase conveying is a possibility, but only for materials that are naturally capable of being conveyed at low velocity, since this is a conventional type of conveying facility.

Although the data presented is derived from a high pressure conveying facility, low pressure results are also included within the overall conveying characteristics, and so this area is equally appropriate for low pressure conveying systems. The data is simply compressed into a small area, rather than being magnified, as with Figures 11.1 to 11.4.

The authors have conveyed a considerable number of different materials through one particular pipeline and a sketch of this was presented earlier in Figure 4.2. This is also a two inch nominal bore pipeline and materials were fed into the pipeline by means of a blow tank once again, for the same reasons as outlined above for the low pressure conveying data. In this case it was a high pressure, top discharge, blow tank with a pressure rating of 100 lbf/in² gauge. The air supply came from a reciprocating compressor capable of delivering 200 ft³/min of free air at a pressure of 100 lbf/in² gauge.

Conveying characteristics are presented for a copper-zinc catalyst, potassium chloride, magnesium sulfate and potassium sulfate in Figure 11.8. It will be noted that not one of these materials could be conveyed in dense phase and at low velocity, despite the availability of high pressure air. As with the group of materials considered above, that were conveyed in a low pressure conveying system, there was little difference in minimum conveying air velocities for these materials either. Both the potassium chloride and magnesium sulfate required 2600 ft/min, the potassium sulfate 2800 ft/min and the catalyst 2900 ft/min.

For consistency, and ease of visual comparison, this set of conveying characteristics have been drawn to the same scale as those for other materials conveyed through this same pipeline and presented earlier. From the group of materials presented in Figure 11.8 only the catalyst came close to being conveyed at 20,000 lb/h. It will be noted that the iron powder (Figure 4.17) was conveyed at 40,000 lb/h, and 55,000 lb/h was achieved with both the cement (Figure 4.5b) and the fly ash (Figure 4.10a). For reference the other materials are alumina (4.8b), coal (10.25, 26 & 29), silica sand (4.10b) and a group in Figure 4.17.
Figure 11.8 Conveying characteristics for high pressure conveying of various materials conveyed through the pipeline shown in Figure 4.2. (a) A Cu-Zn catalyst, (b) potassium chloride, (c) magnesium sulfate, and (d) potassium sulfate.
3.1 Conveying Capability

In order to complete the picture with regard to material conveying capability at this point, two further materials conveyed through the Figure 4.2 pipeline are presented. One is barite and the other is polyethylene pellets and this data is presented in Figure 11.9.

These conveying characteristics are also drawn to the same scale as those for the materials in Figure 11.8. Both of the additional materials could be conveyed with air flow rates as low as 20 ft/min and hence with conveying line inlet air velocities of only 600 ft/min, which relates to dense phase flow. Although the conveying air velocity range is the same for both materials, values of solids loading ratios, and the slope of the constant pressure lines at low values of air flow rate, are completely different.

The barite had a mean particle size of about 15 micron and so had very good air retention properties. As a consequence the material could be conveyed very well in a sliding bed mode of flow, since the necessary pressure gradient was available for conveying with the above test facility. These points are discussed in some detail in Chapter 4.

![Figure 11.9](image)

**Figure 11.9** Conveying characteristics for materials capable of low velocity dense phase flow conveyed through the pipeline shown in figure 4.2. (a) Barite and (b) polyethylene pellets.
The polyethylene pellets had a mean particle size of about 0.15 in (4 mm) and a particle density of about 57 lb/ft³. The main feature, however, was that the particles were all uniform and so there was virtually no separate particle size distribution. As a consequence the material had very good permeability and so would convey in dense phase, at low velocity, in a conventional pneumatic conveying system, in plug type flow.

The very high permeability accounts for the relatively low maximum value of solids loading ratio achieved. Powdered materials have almost no permeability, but have very good air retention properties, and so very high values of solids loading ratio can be achieved, particularly if high pressure gradients are available for conveying.

Although the material will convey with air velocities down to 600 ft/min, material flow rates are low at low air flow rates. There is a marked pressure minimum with this type of conveying characteristic, such that below the pressure minimum a decrease in air flow rate will result in a decrease in material flow rate for a given air supply pressure.

If particle melting, and the formation of ‘angel hairs’ is a problem with this type of material, however, low velocity conveying is an option for minimizing the problem. The conveying characteristics of this type of material are considered further in a later section in this chapter.

3.2 Dilute Phase Conveying

Two of the materials that performed very poorly in the Figure 4 pipeline were magnesium sulfate and potassium sulfate. They were poor performers only in terms of the material flow rates achieved, but presented no more difficulties in conveying than any other material. Further high pressure conveying data for these two materials conveyed through the Figure 7.13 pipeline is presented in Figure 11.10. This pipeline was 310 feet long and 3 inch nominal bore and 400 ft³/min of free air was available for conveying.

If the data for the magnesium sulfate from Figure 11.8 is compared with that from Figure 11.10 it will be seen that the maximum material flow rate for a conveying line pressure drop of 30 lbf/in² has increased from about 13,000 lb/h to 25,000 lb/h. The maximum material flow rate for the potassium sulfate, for a pressure drop of 25 lbf/in² has increased from about 8,000 lb/h to 15,000 lb/h. This clearly shows the influence of pipeline bore in terms of increasing the flow rate of a material in a pneumatic conveying system.

The increase in material flow rates in the above cases is approximately 90%. This is despite the fact that the three inch bore pipeline is about 90% longer than the two inch bore pipeline. The two pipelines, however, have exactly the same number of bends. Scaling parameters based on the use of conveying data are considered in Chapter 15. These can take account of differences between the bore, length, pipeline orientation, and number and geometry of bends, such as that between a test facility and a plant pipeline.
3.3 Material Grade

Great care must be exercised when a specific name is given to a material. Many materials are available in a variety of grades and it is quite possible for the conveying characteristics for different grades to be very different from one another. A particular case is that of pulverized fuel ash, and this was considered in some detail in Chapter 10. Although it is exactly the same material, the ash collected in different hoppers in a boiler plant will have very different particle size distributions. That collected in the economizer hoppers, close to the combustion zone, will generally be very coarse and have no dense phase conveying capability at all. That collected in the electrostatic precipitator hoppers, furthest from the combustion zone, will be a very fine powder and will convey in dense phase very well. The differences in conveying capability were clearly illustrated in Figure 10.14.

Data for the conveying of two grades of dicalcium phosphate is included in Figure 11.11. These materials were also conveyed through the three inch nominal bore pipeline shown in Figure 7.13. One is referred to as 48% dicalcium phosphate and the other as 52% dicalcium phosphate. Although they have the same name the conveying performance of the two materials is widely different. The 48% material was a fine powder with very good air retention properties and the 52% was a coarse granulated material with neither good air retention nor permeability.

Figure 11.10  Conveying characteristics for materials conveyed through the pipeline shown in Figure 7.13 (a) Magnesium sulfate and (b) potassium sulfate.
Figure 11.11 Conveying characteristics for (a) 48% grade and (b) 52% grade of dicalcium phosphate conveyed through the pipeline shown in Figure 7.13.

It will be seen that the axes for the material flow rate on the Figure 11.11 axes had to be doubled from that employed on Figure 11.10 in order to accommodate the data for the 48% dicalcium phosphate. The material flow rate achieved with the 52% dicalcium phosphate was less than one-third of that for the 48% grade, and only marginally better than that for the potassium sulfate in Figure 11.10. Maximum values of solids loading ratios achieved differ by a factor of about ten to one.

3.4 Degraded Material

For materials that are very friable it is possible for them to degrade as a result of being pneumatically conveyed. As a direct consequence of this it is possible for the conveying performance of the material to change. This is essentially an extension of the issue discussed above on the influence of material grade. Degradation of the material, as a result of conveying, can effectively cause a change in the grade of the material.

This is particularly a problem with materials that border on the edge of the sliding bed mode of conveying capability. Such materials are typically fine granular but do not have sufficient air retention to be capable of dense phase conveying. The fines generated while conveying the material, however, will cause an increase
in the air retention properties of the material and this, in turn, will result in a gradual lowering of the minimum velocity at which the material can be conveyed.

These issues are illustrated with Figure 11.12 which presents conveying characteristics for sodium sulfate. Once again they relate to the 310 ft long pipeline of three inch nominal bore shown in Figure 7.13. Figure 11.12a is for the material in the 'as supplied' condition and Figure 11.12b is for exactly the same material after it had been re-circulated a number of times. It will be seen that there are significant changes in both the minimum conveying air velocity at which the material could be conveyed and the material flow rate achieved for a given value of conveying line pressure drop. As a result of these two changes there has also been a significant increase in the value of the solids loading ratio at which the material could be conveyed.

The conveying capability of the degraded material shown in Figure 11.12b is sometimes referred to as 'medium phase' conveying. This is not a common situation because of the specific material properties required. In true dense phase conveying solids loading ratios of over 100 would be achieved with a conveying line pressure drop of 30 lbf/in² in a pipeline of this length, as demonstrated with the dicalcium phosphate in Figure 11.11a.

![Figure 11.12](image)

**Figure 11.12** Conveying characteristics for (a) fresh and (b) degraded sodium sulfate conveyed through the pipeline shown in figure 7.13.
If the material were to be re-circulated and degraded further it is likely that conveying would be possible at progressively lower velocities and higher solids loading ratios. For materials with no dense phase conveying capability it is unlikely that they could be conveyed at a solids loading ratio much higher than 25 with a conveying line pressure drop of 30 lbf/in$^2$ in a pipeline of this length.

If dramatic changes such as these occur to a material over relatively short conveying distances, it is generally necessary to undertake conveying trials with fresh material every time it is conveyed. If this is not done serious errors can result if conveying characteristics such as those presented here are to be produced. The issue of material degradation as a result of re-circulating is considered in more detail in relation to soda ash later in this chapter.

3.5 Plastic Materials

On Figure 11.2 the low pressure conveying characteristics for PVC resin powder were shown to exhibit a pressure minimum point, with the material flow rate decreasing with decrease in air flow rate beyond the optimum point. This type of material does appear to exhibit this particular characteristic, being a combination of the conveying characteristics for conventional powders and those for plastic pellets. This particular material was also conveyed in a high pressure test facility and a sketch giving appropriate details of this for reference is presented in Figure 11.13 [2].

Data for two materials conveyed through this two inch nominal bore pipeline is presented in Figure 11.14. The materials presented are the PVC resin powder and terephthalic acid (PTA). Both materials were conveyed with conveying line pressure drop values of up to 30 lbf/in$^2$ and both were clearly capable of being conveyed in dense phase.

![Pipeline Diagram](image)

**Figure 11.13** Details of pipeline used for the high pressure conveying of various plastic materials.
Both materials exhibited marked pressure minimum points, with that for the terephthalic acid being at a much lower air flow rate, and hence lower velocity, than the PVC resin. As a consequence much higher material flow rates and solids loading ratios were obtained with the terephthalic acid than for the PVC.

The reason for the change in slope from negative to positive for the constant pressure lines at low air flow rates is not fully understood. The pressure drop curves for the materials presented on Figure 11.14 may appear to be more logical, as it could be argued that the pressure drop curves might be expected to pass through the origin, or close to it, as one would expect no material flow rate with no air flow. At very high air flow rates all of these curves have a negative slope and these are consistent with a square law influence of velocity on pressure drop, and hence frictional forces dominating in this region.

Although powdered materials of a non-plastic type are mostly depicted as maintaining a negative slope throughout the range of conveying capability, as presented in these notes, work with pulverized fuel ash has shown this same characteristic [3]. It generally occurs at extremely low values of conveying air velocity and so tends not to be included in conveying data, as it is generally too low for practical application.
The pipeline shown in Figure 11.13 is very similar in terms of distance and geometry to that of the Figure 4.2 pipeline and so the data for the materials presented in Figure 11.12 can be compared reasonably well with that for the materials shown in Figures 11.8 and 11.9.

It will be seen that the material flow rates obtained with both the PVC resin and the terephthalic acid were much higher than any of the materials presented in Figure 11.8. This is due, in part to the fact that the plastic materials could be conveyed in dense phase, and hence at very much lower air flow rates. In comparison with the barite in Figure 11.9, however, material flow rates were significantly lower.

### 3.6 Pelletized Materials

Conveying characteristics for polyethylene pellets were presented earlier in Figure 11.9. These were derived for flow through a two inch nominal bore pipeline. In analyzing the conveying data to produce the conveying characteristics it was found that the lines of constant conveying line pressure drop gradually merged together as the air flow rate reduced and it was felt that this was a function of the relatively small bore pipeline employed.

In a similar program of conveying trials, carried out with nylon pellets in a three inch bore pipeline, it was possible to achieve an effective magnification of this area. A sketch of the pipeline used for the conveying trials with the nylon pellets is given in Figure 11.15 for reference. A high pressure, bottom discharge blow tank, was used for feeding the material into the pipeline. The nylon pellets had a similar mean particle size to that of the polyethylene pellets, being about 0.15 in (4 mm), and were essentially mono-sized once again.

**Figure 11.15** Details of pipeline used for the high pressure conveying of nylon pellets.
Materials that will naturally convey in dense phase plug type flow require a very high value of permeability and so this mode of conveying is limited to materials such as grains, seeds and pellets that have a very narrow particle size distribution. The conveying characteristics for nylon pellets conveyed through the three inch nominal bore pipeline shown in Figure 11.15 are presented in Figure 11.16a. This shows that the lines of constant conveying line pressure drop are very close together in the dense phase conveying region, at low air flow rates. Once again the maximum value of solids loading ratio is only about thirty.

In Figure 11.16b the conveying characteristics for the nylon pellets are presented in terms of pressure drop plotted against air flow rate, with material flow rate as the family of curves. In many text books and articles on the subject of pneumatic conveying this is commonly the form of presenting these relationships, either with logarithmic axes or no scales at all, and are generally for illustration purposes only. It is also more difficult to add lines of constant solids loading ratio to this plot. This form of presentation, however, clearly shows that a pressure minimum occurs with this material, such that there is a clearly defined value of air flow rate at which the conveying line pressure drop is a minimum for a given material flow rate.

![Diagram](image)

**Figure 11.16** Nylon pellets conveyed through the pipeline shown in figure 11.15. (a) Conveying characteristics and (b) pressure drop data.
From Figure 11.16a it will be seen that the pressure minimum point occurs at a gradually reducing value of air flow rate as the value of conveying line pressure drop decreases. This pressure minimum point does, in fact, occur at a conveying line inlet air velocity of approximately 2600 ft/min over the entire range of pressures investigated. Above this velocity the conveying characteristics are very similar to those of any other material conveyed in dilute phase, suspension flow. 2600 ft/min is approximately the minimum value of conveying air velocity for the dilute phase conveying of this material. This point is considered further later in this chapter.

The material, however, is clearly capable of being conveyed at much lower velocities than 2600 ft/min and it is also clear that at the pressure minimum point the mode of flow starts to change to one of plug flow, with reduction in air flow rate. Some materials have a smooth transition from dilute to dense phase flow with reduction in air flow rate, some show very erratic and unreliable behavior in this region, and others have a band of velocity values across which they cannot be conveyed, but when the velocity reduces to about 1000 or 1200 ft/min most materials of this type will be capable of dense phase plug type flow in a conventional conveying system.

3.7 Soda Ash

Light sodium carbonate (light soda ash) typically has a mean particle size of about 115 micron and has something of a reputation for being a difficult material to convey. It is a friable material and slightly hygroscopic. In order to learn something of its conveying capability a controlled program of conveying trials was undertaken [4]. A sketch of the pipeline used for this test work is given in Figure 11.17. A high pressure, bottom discharge blow tank, was used for feeding the material into the pipeline.

**Figure 11.17** Details of pipeline used for the high pressure conveying of soda ash.
The normal procedure in obtaining a set of conveying characteristics for a material is to load a sample of the material into the supply hopper of the test facility and to recirculate the material. Each time the material is conveyed, the air flow rate, material flow rate and/or the air supply pressure are varied in order to achieve as wide a spread of test data as possible. It is normal practice to repeat tests on a sequential basis in order to ensure that the recirculation of the material is not causing any change in the conveying characteristics. This was observed with the soda ash, and it was so marked that it was decided that the conveying characteristics should be obtained on the basis of using fresh material for every test run.

The conveying characteristics determined for the soda ash on the basis of using fresh material for every test are presented in Figure 11.18a. The conveying characteristics obtained in the usual way, with material constantly recirculated, are presented in Figure 11.18b for reference and comparison.

With many materials, when they become degraded, there is a tendency for them to achieve a degree of air retention, and to have the capability of being conveyed at a much lower velocity, as was the case with the sodium sulfate reported earlier in Figure 11.12. With the soda ash the main influence was on the conveyability of the material, in terms of the mass flow rate of the material achieved, for a given value of conveying line pressure drop, and not to a lower velocity capability.

Figure 11.18 Conveying characteristics for soda ash conveyed through the pipeline shown in Figure 11.17 (a) Fresh material and (b) re-circulated material.
As will be seen from Figure 11.18a, the fresh material had a degree of dense phase conveying capability since it could be conveyed at solids loading ratios of up to about 60. Although higher values of solids loading ratio were achieved with the degraded material this was due to the fact that higher material flow rates were achieved. The fresh material showed a marked pressure minimum point in the conveying characteristics, whereas the degraded material showed no change in slope of the constant conveying line pressure drop curves with reduction in air flow rate.

3.7.1 Particle Size Changes

For reference purposes a batch of material was re-circulated and samples were taken after every pass to show how the recirculation influenced the mean particle size. For consistency the same air and material flow rates were maintained each time the material was re-circulated. A typical set of results is shown in Figure 11.19. This is a plot of the mean particle size of the soda ash every time it was conveyed.

The pipeline was only 120 ft long, with a total of five bends, but in the case illustrated the material degraded from a mean particle size of about 117 micron to 97 micron in the first pass. After ten passes the mean particle size had reduced to about 73 micron. The maximum value of conveying air velocity was only 3500 ft/min in this program of tests, in an attempt to minimize degradation. For the very first pass the conveying line pressure drop was about 44 lbf/in² and so the conveying line inlet air velocity in this case was about 900 ft/min.

\[
\begin{align*}
\dot{V}_o &= 80 \text{ ft}^3/\text{min} \\
\dot{m}_p &= 30,000 \text{ lb/h} \\
C_{\text{max}} &= 3,500 \text{ ft/min}
\end{align*}
\]

Figure 11.19 The influence of material recirculation on the mean particle size of the soda ash.
3.7.2 Pressure Drop Changes

In the program of tests reported above, the material was conveyed with exactly the same air flow rate, and the material was conveyed at a rate of 30,000 lb/h each time. Every time the material was conveyed, therefore, the value of the conveying line pressure drop was recorded.

The influence of material re-circulation on the conveying line pressure drop is shown in Figure 11.20. As mentioned above this was about 44 lbf/in² for the first pass and it had reduced to about 27 lbf/in² for the tenth and last pass. From this it will be seen that there was a gradual, but very significant, reduction in pressure drop as the material was conveyed.

From the complete sets of conveying characteristics for the fresh and re-circulated materials the 15 lbf/in² pressure drop lines have been compared on Figure 11.21. This shows quite clearly the very significant differences that there are between the two samples of material. It is interesting that the difference in material flow rates between the two increases with decreasing air flow rate, and hence with reducing conveying air velocity.

This, however, relates to the change in the nature of the conveying characteristics for the material, as discussed above. The fresh material clearly has a pressure minimum point, at a conveying line inlet air velocity of about 3000 ft/min, and the degraded material is typical of the majority of powdered materials in displaying no pressure minimum point. This is another aspect of pneumatic conveying that is not fully understood at the present time.

\[ v_o = 80 \text{ ft}/\text{min} \]
\[ \dot{m}_p = 30,000 \text{ lb/h} \]
\[ C_{max} = 3,500 \text{ ft/min} \]

Figure 11.20 The influence of material recirculation on conveying line pressure drop for the soda ash.
4 MULTIPLE MATERIAL CONVEYING

Not all pneumatic conveying systems are dedicated to the conveying of a single material. There is often a need for a system to transport a number of different materials. In food related industries, in particular, a wide variety of materials have to be conveyed by a common system, since there is a requirement to deliver a given ‘menu’ for a particular process.

Some of the materials to be transported may be capable of being conveyed in dense phase, and hence at low velocity, while others may have no dense phase conveying capability and will have to be conveyed in dilute phase with a high conveying air velocity. This is illustrated with the case of wheat flour and granulated sugar, conveyed through the same pipeline. Conveying characteristics for these two materials, conveyed through the Figure 4.4 pipeline, are presented in Figure 11.22.

There is often a requirement for these two materials to be conveyed through a common pipeline. From the conveying characteristics presented in Figure 11.22, however, it will be seen that there are considerable differences in the conveying capabilities of these two materials. Wheat flour can be conveyed in dense phase and with conveying air velocities down to about 600 ft/min, and with a conveying line pressure drop of 25 lbf/in² a material flow rate of about 24,000 lb/h can be achieved with a free air flow rate of about 45 ft³/min.

Figure 11.21 Comparison of pressure characteristics for fresh and re-circulated soda ash.
Granulated sugar, however, can only be conveyed in dilute phase and requires a minimum conveying air velocity of about 3200 ft/min, and with the same pressure drop of 25 lbf/in² a material flow rate of only 15,000 lb/h can be achieved and this requires a free air flow rate of about 185 ft²/min.

There are a multitude of different possibilities for conveying both of these materials with a common system. Some of these are outlined below:

☐ One would be to control the volumetric flow rate of the air for the flour so that both materials are conveyed under the optimum conditions detailed above. Changing air flow rates for each material is not always possible or convenient, however, and if the surplus air had to be discharged to atmosphere it would be a very significant waste of energy.

☐ If a larger bore pipeline could be used to convey the flour no change need be made to the common air supply. In the above case the diameter of the pipeline could be increased to 4 inches. This would reduce the conveying line inlet air velocity to 800 ft/min for the flour and increase the material flow rate to about 96,000 lb/h.

☐ If it was necessary to use the same pipeline bore and air flow rate for both materials, the flow rate for the flour will reduce to about 13,000 lb/h,
as will be seen from Figure 11.22a, which is less than that for the sugar, and is clearly a very inefficient option.

If an air flow rate of 45 ft³/min was to be used for both materials, 24,000 lb/h of flour would be conveyed, but as will be seen from Figure 11.22b, there would be no possibility of conveying any sugar. Only if the diameter of the pipeline for the sugar was reduced to one inch would it be possible to convey the sugar with 45 ft³/min at 25 psig, but the material flow rate would be reduced to about 3,000 lb/h, which is unlikely to be acceptable.

A further possibility is to use a smaller bore pipeline for the sugar and to step the diameter to a larger bore along its length. By this means exactly the same air supply could be used for both materials and a common pipeline could be used to feed the materials into the reception hopper, if required. A sketch of such a system is given in Figure 11.23. It is based on the use of a 10 inch bore pipeline for the flour, with an air supply of 2250 ft³/min of free air delivered at 30 lbf/in² gauge.

For the given air supply specification of 2250 ft³/min of free air at 30 lbf/in² gauge and the pipeline bores indicated on Figure 11.23, the velocity profiles for the flow of the two materials through the two pipelines are presented in Figure 11.24. By using a 6 inch bore pipeline for the sugar it will be seen that a pick-up velocity of about 3770 ft/min could be achieved and by stepping up to 8 and then 10 inch bore, as shown on Figure 11.24, the minimum conveying air velocity could be kept at about this value throughout the pipeline. For the flour the pick-up velocity would be about 1360 ft/min, expanding to about 4125 ft/min.

![Figure 11.23 Sketch of a typical positive pressure conveying system for conveying diverse materials and utilizing a stepped pipeline.](image)
Figure 11.24  Velocity profiles for conveying diverse materials in a common system.

If there was not a need for the two pipelines to be a common diameter to feed into the reception hopper a separate 12 inch bore pipeline could be used, for which the pick-up and exit velocities would have been 940 and 2860 ft/min respectively.

Although 940 ft/min is satisfactory for the inlet velocity, the relatively low exit velocity will mean that it will take a little longer to completely purge the pipeline should this be a requirement for the material. This point was considered earlier with Figure 9.3 where purging of stepped pipelines was considered in some detail. In the previous chapter a similar conveying duty was considered with respect to different grades of fly ash, but a vacuum conveying system was used in that case.

5 CONVEYING AIR VELOCITIES

In order to illustrate further, and so reinforce the importance of conveying air velocity, the conveying characteristics for three representative materials presented here have been magnified and lines of constant conveying line inlet air velocity have been superimposed. This is the minimum value of conveying air velocity in the pipeline, which occurs at the material feed point into the conveying pipeline, whether the system is a positive pressure or vacuum conveying system, and is commonly referred to as the ‘pick-up’ velocity.
Conveying characteristics for the 52% grade of dicalcium phosphate conveyed through the Figure 7.13 pipeline, with pick-up velocities superimposed, are presented in Figure 11.25. Lines of constant pick-up, or conveying line inlet air velocity, can be superimposed on the conveying characteristics quite easily. This is purely a mathematical process [5]. It is simply a function of the free air flow rate, the conveying line inlet air pressure and the pipeline bore, for a given air temperature. The horizontal axis could also have been presented in terms of conveying line exit air velocity, for as the conveying line exit air pressure in a positive pressure conveying system is atmospheric pressure, and hence constant, it is a direct conversion, unlike inlet air velocity.

These new conveying characteristics for the 52% dicalcium phosphate are typical of all the materials presented earlier that are only capable of being conveyed in dilute phase suspension flow. For this particular material the minimum value of conveying air velocity that could be used was about 2400 ft/min. For system design purposes a 20% margin would generally be suggested and so a conveying line inlet air velocity of about 2900 ft/min would be recommended.

Similar conveying characteristics for the 48% grade of dicalcium phosphate from Figure 11.11a also with pick-up velocities superimposed, are presented in Figure 11.26. These are also typical of all the materials presented earlier that are capable of being conveyed at low velocity in dense phase in a sliding bed mode of non-suspension flow. The minimum conveying air velocity for this material was about 600 ft/min.
Once again a 20% margin on the minimum value would be suggested for the pick-up velocity for design purposes. The operating envelope for the conveying of this type of material at low velocity is very wide and so system control is not generally a problem, provided that the minimum conveying air velocity is always a reasonable margin above that dictated by the corresponding value of solids loading ratio. This was considered earlier at Figures 4.6 and 7.23.

Similar data for the nylon pellets presented earlier in Figure 11.16a are shown in Figure 11.27. Because of the positive slope to the lines of constant conveying line pressure drop at low air flow rate, the operating envelope for the conveying of this type of material at low velocity is very limited. As a consequence conveying line pressure drop may be difficult to control. This particular aspect of the problem is shown more clearly with the pressure drop versus air flow rate plot in Figure 11.16b.

5.1 Minimum Conveying Air Velocities

The minimum values of conveying air velocity for some of the materials reported here are presented below in Table 11.1. Extreme caution must be taken in using such data, for small changes in grade and characteristics of a given material can have a significant influence on the value of minimum velocity. It would normally be recommended that a conveying line inlet air velocity about 20% greater than the minimum conveying air velocity value reported should be used for the design of any conveying system, as considered above.
Figure 11.27 Conveying characteristics for nylon pellets with pick-up velocities superimposed.

Table 11.1 Conveying Data

<table>
<thead>
<tr>
<th>Material</th>
<th>Location of Data</th>
<th>Minimum Conveying Air Velocity - ft/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonium Chloride</td>
<td>11.1</td>
<td>2400</td>
</tr>
<tr>
<td>Barite</td>
<td>11.9a</td>
<td>2400</td>
</tr>
<tr>
<td>Cu-Zn Catalyst</td>
<td>11.8a</td>
<td>2900</td>
</tr>
<tr>
<td>Dicalcium Phosphate:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>48%</td>
<td>11.11a</td>
<td>2100</td>
</tr>
<tr>
<td></td>
<td>11.2</td>
<td></td>
</tr>
<tr>
<td>52%</td>
<td>11.11b</td>
<td>2400</td>
</tr>
<tr>
<td></td>
<td>11.25</td>
<td></td>
</tr>
<tr>
<td>Magnesium Sulfate</td>
<td>11.8c</td>
<td>2600</td>
</tr>
<tr>
<td></td>
<td>11.10a</td>
<td></td>
</tr>
</tbody>
</table>
Table 11.1 Conveying Data - Continued

<table>
<thead>
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<th>Material</th>
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</thead>
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<tr>
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<td></td>
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<tr>
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<td>11.16a</td>
</tr>
<tr>
<td></td>
<td>11.27</td>
<td>11.27</td>
</tr>
<tr>
<td>Polyethylene Pellets</td>
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<td>Potassium Chloride</td>
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<tr>
<td>Potassium Sulfate</td>
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<tr>
<td></td>
<td>11.10b</td>
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<tr>
<td>PVC Resin</td>
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<tr>
<td></td>
<td>11.14b</td>
<td>11.14b</td>
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<tr>
<td>Sodium Carbonate:</td>
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</tr>
<tr>
<td>Heavy Soda Ash</td>
<td>11.4</td>
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</tr>
<tr>
<td>Light Soda Ash</td>
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<td>11.18a</td>
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<td>Sodium Chloride</td>
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<td>Sodium Sulfate</td>
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<td>Sugar - Granulated</td>
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<tr>
<td>Wheat Flour</td>
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</table>

REFERENCES


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