1 INTRODUCTION

The aluminum industry employs pneumatic conveying widely for its materials handling processes. As with many industries, there is economy in scale, and so individual plants tend to be very large. It is still very much an expanding industry, and an industry that most large countries in the world like to have as part of their industrial infrastructure, particularly if cheap power is available from hydro-electric sources or from surplus gas reserves.

The economy of scale is such that alumina is one of the major bulk solids that is widely transported around the world by bulk carrier. At ports, ship off-loading systems based on pneumatic conveying of the material are commonly employed, such as that depicted in Figure 1.7. Over-land transport is generally by rail vehicles and these often have the capability of being pressurized to about 30 lbf/in$^2$ gauge so that they can be off-loaded by positive pressure conveying systems in a reasonably short period of time.

1.1 Systems and Components

The first point to note about alumina is that it is a very abrasive material. As a consequence this must feature prominently in all decisions made with regard to the selection of systems and components.
This is one of the industries that tends to employ fluidized motion conveying systems. This type of conveying system was introduced in section 7 of Chapter 1 and are considered in some detail in Chapter 18. Air-assisted gravity conveyors have been quite widely used for fifty years or more, but the more recent innovation of full channel conveyors are gaining wider acceptance for alumina. A particular advantage of this type of system is that the air requirements are very low and the transport velocity is also very low, and so problems of wear associated with alumina are significantly reduced.

This is also an industry where innovatory pneumatic conveying systems are employed. This type of system was introduced in section 6 of Chapter 1 and are considered in more detail in Chapter 17. Plug forming systems based on internal by-pass pipes are probably the most commonly used system. This, once again, is as a consequence of the abrasive nature of the materials conveyed.

This type of system, however, should only be used when actually required, and this is dictated by the grade of the material. If a material has good air retention properties it will convey quite naturally in dense phase and at low velocity in a conventional pneumatic conveying system, and an innovatory system would be quite unnecessary.

With regard to pipeline feeding devices, the ideal requirement is that the feeder should have no moving parts, particularly if there is a pressure drop across the feeder. Blow tanks, therefore, are widely used. If it is necessary to use a rotary valve then it will have to be made of appropriate wear resistant materials, for both the rotor and casing, and an increase in air leakage with respect to time must be anticipated for the feeder.

2 MATERIAL GRADE

Alumina is another material that comes in a range of grades, and the grades are such that the material may be a powder having good air retention properties, in which case it may be capable of being conveyed in dense phase. Alternatively, if it comes as a fine granular material with very poor air retention it will probably only be capable of being conveyed in dilute phase in a conventional pneumatic conveying system. It is a fine division between the two, as was considered in the previous chapter, with regard to the degradation of fine granular materials.

Alumina in fine powdered form is often referred to as floury alumina and is generally capable of being conveyed naturally in dense phase and hence at low velocity. Fine granular alumina is often referred to as sandy alumina and this is generally only capable of being conveyed in dilute phase suspension flow. The conveying characteristics for two typical grades of alumina were presented in Figure 9.11 in relation to the use of stepped pipelines for the conveying of diverse materials. In order to reinforce, at the outset, this important point of the influence of material grade on pneumatic conveying performance, these conveying characteristics are reproduced here in Figure 12.1.
Figure 12.1 Conveying characteristics for (a) floury and (b) sandy grades of alumina.

A sketch of the two inch nominal bore pipeline through which these two materials were conveyed is presented in Figure 12.2 for reference. A high pressure bottom discharge blow tank was used to feed the materials into the pipeline.

Figure 12.2 Details of pipeline used for the conveying of the two grades of alumina presented in figure 12.1.
As a consequence of the relatively short length of the pipeline, and the high pressure air available for conveying, solids loading ratios of up to 200 were achieved with the floury alumina. Values up to about 40 were achieved with the sandy alumina, but despite the high pressure air available, the material could not be conveyed in dense phase and at low velocity.

### 2.1 Conveying Air Velocities

More detailed conveying data for this floury grade of alumina is presented in Figure 12.3, with lines of constant conveying line inlet air velocity also superimposed. On this plot a second horizontal axis has been added. This is of conveying line exit air velocity. Since the conveyed material at the end of the pipeline is always at atmospheric pressure, conveying line exit air velocity is directly proportional to free air flow rate and so both axes apply.

With both conveying line inlet and exit values of conveying air velocity represented, the magnitude of the expansion of the air through the pipeline can be clearly seen. From points on the 45 lbf/in² pressure drop curve, for example, it will be seen that the conveying air velocity expands by a factor of approximately four times between inlet and outlet. This is due to the fact that absolute values of pressure, and temperature, have to be used in all equations associated with the compressible flow of air.

![Figure 12.3](image)

**Figure 12.3** Conveying data for floury alumina conveyed through the pipeline shown in Figure 12.2
Similar data for the sandy grade of alumina is presented in Figure 12.4. With this material the minimum conveying air velocity was always above 2000 ft/min, and although the minimum value of conveying air velocity reduced slightly with increase in air supply pressure, it was only marginal.

3 LOW PRESSURE CONVEYING

As mentioned before, low pressure dilute phase conveying data is generally included in the conveying characteristics derived with high pressure conveying facilities, and so this data is equally valid. Care must be exercised, however, in ensuring that the appropriate minimum conveying air velocity is used.

Both calcined alumina and hydrate of alumina have been conveyed through the Figure 10.16 pipeline of two inch nominal bore and 110 feet long. The low pressure conveying characteristics for these two materials are presented in Figure 12.5. In terms of conveying capability there is little difference between the two materials. The hydrate of alumina shows a tendency to a pressure minimum point at low air flow rates and so the material flow rate in this region is slightly lower than that for the calcined alumina.

There is also a slight difference in minimum conveying air velocities between the two materials. That for the calcined alumina is about 2300 ft/min and that for the hydrate of alumina is about 2500 ft/min.
Figure 12.5  Conveying characteristics for (a) calcined and (b) hydrate of alumina conveyed through the pipeline shown in Figure 10.16.

Cumulative particle size distributions for the two materials are presented in Figure 12.6 for reference.

Figure 12.6  Cumulative particle size distributions for alumina materials in figure 12.5.
The mean particle size for the calcined alumina was about 66 \( \mu m \) and that for the hydrate of alumina was about 60 \( \mu m \). Granular materials, such as these, generally do not have sufficient air retention at this mean particle size for them to be capable of being conveyed in dense phase in a conventional conveying system. It is unlikely, therefore, that either of these materials could be conveyed in dense phase, even if a much higher air supply pressure were available. The particle density for the calcined alumina was about 245 lb/ft\(^3\) and that for the hydrate of alumina was about 150 lb/ft\(^3\).

4 HIGH PRESSURE CONVEYING

Both the calcined alumina and the hydrate of alumina have been conveyed in high pressure conveying facilities and it will be seen that they could not be conveyed in dense phase and at low velocity, despite the high pressure. Data on a number of other materials, such as aluminum fluoride, fluorspar and cryolite is also presented.

4.1 Calcined Alumina

Conveying characteristics for calcined alumina conveyed through the Figure 7.13 pipeline of three inch nominal bore are presented in Figure 12.7. The minimum value of conveying air velocity for the material was about 2300 ft/min.

![Figure 12.7 Conveying characteristics for calcined alumina conveyed through the pipeline shown in figure 7.13.](image)
It will be seen that the maximum value of solids loading ratio for the calcined alumina was just over 12 in Figure 12.7 and that a similar value was obtained for the material in the low pressure test facility in Figure 12.5a. This is due to the fact that the material could only be conveyed in dilute phase suspension flow in both cases, and that the pressure gradients for the two pipelines were very similar. The Figure 10.16 pipeline was 110 feet long and the maximum value of pressure drop was 8 lbf/in\(^2\), and the Figure 7.13 pipeline was 310 feet long with a maximum pressure drop of 25 lbf/in\(^2\). The approximate factors of three in terms of pipeline length and pressure drop cancel each other out.

For reference and comparison purposes, a number of other materials conveyed through the Figure 7.13 pipeline were presented in Figures 11.10 to 11.12, including potassium sulfate and dicalcium phosphate. These show a very wide range of conveying capabilities.

### 4.2 Hydrate of Alumina

A sketch of the high pressure pipeline facility in which the hydrate of alumina was conveyed is presented in Figure 12.8. It was a two inch nominal bore pipeline, 320 feet in length and incorporated thirteen 90\(^\circ\) bends, having a bend diameter, D, to pipe bore, d, ratio of about 24:1. Once again the material was fed into the pipeline by means of a high pressure, top discharge blow tank, having a fluidizing membrane.

The conveying characteristics for the hydrate of alumina conveyed through this pipeline are presented in Figure 12.9.

![Figure 12.8](image_url) Sketch of pipeline used for the high pressure conveying of hydrate of alumina.
As with the calcined alumina, the hydrate of alumina could not be conveyed in dense phase either, despite the availability of high pressure air. The maximum value of solids loading ratio was about 16, which is similar to that achieved in the low pressure conveying trials reported in Figure 12.5, but this is due once again to the commonality of pressure gradients between the two sets of data. The minimum value of conveying air velocity was about 2500 ft/min once again.

4.3 Aluminum Fluoride

Similar data for aluminum fluoride conveyed through the Figure 12.8 pipeline is presented in Figure 12.10. It will be seen that there is little difference between the conveying capability of the aluminum fluoride and the hydrate of alumina. Low velocity, dense phase conveying of this material was not a possibility in the conveying system employed, as with the calcined alumina and hydrate of alumina reported above.

The minimum conveying air velocity for the aluminum fluoride was slightly higher at 2600 ft/min and material flow rates were slightly lower than those for the hydrate of alumina. The bulk density of the hydrate of alumina was about 75 lb/ft$^3$ and that for the aluminum fluoride was about 90 lb/ft$^3$. Such consistency in the conveying characteristics for a group of different materials is unusual.
Figure 12.10  Conveying characteristics for aluminum fluoride conveyed through the pipeline shown in Figure 12.8.

4.4 Fluorspar

A sketch of the high pressure pipeline facility in which fluorspar was conveyed is presented in Figure 12.11. It was a two inch nominal bore pipeline, 230 feet in length and incorporated nine 90° bends, having a bend diameter, D, to pipe bore, d, ratio of about 24:1.

Pipeline:
- length = 230 ft
- bore = 2 in
- bends = 9 × 90°

Figure 12.11  Details of pipeline used for high pressure conveying of fluorspar.
The fluorspar was fed into the pipeline by means of a high pressure top discharge blow tank, having a fluidizing membrane. The fluorspar had a particle density of about 230 lb/ft$^3$ and a bulk density of about 100 lb/ft$^3$, which is the highest among the group of materials considered in this chapter. The mean particle size of the material was approximately 66 micron. At this particle size the alumina could not be conveyed in dense phase, but the fluorspar had a degree of air retention. The conveying characteristics for the fluorspar conveyed through the Figure 12.11 pipeline are presented in Figure 12.12.

From Figure 12.12 it will be seen that the fluorspar was able to be conveyed at solids loading ratios of up to about 70. This is very much an intermediate value of solids loading ratio and it is suggested that it is another case of 'medium phase' conveying. This was referred to in the previous chapter with regard to sodium sulfate in Figure 11.12, and in Chapter 10 with regard to pulverized coal in Figure 10.25.

The minimum value of conveying air velocity for the fluorspar was about 1400 ft/min for conveying line inlet air pressures above about 20 psig. At low pressure, and for the dilute phase suspension flow of the fluorspar, the minimum conveying air velocity was about 2500 ft/min.

![Figure 12.12](image_url)

**Figure 12.12** Conveying characteristics for fluorspar conveyed through the pipeline shown in Figure 12.11.
In the next chapter, conveying data for barite, bentonite and cement, each conveyed through the Figure 12.11 pipeline, were all capable of being conveyed at solids loading ratios of well over 100 and at conveying air velocities down to 600 ft/min. Then in Chapter 14 data for silica sand having a mean particle size of approximately 70 micron is presented and the maximum value of solids loading ratio is about 25, with a corresponding conveying line inlet air velocity of about 2300 ft/min. These are typical of the operating limits for dense and dilute phase conveying for high pressure conveying in a pipeline of this length.

4.5 Cryolite

Cryolite is variously referred to as crushed bath and bath material. It has a mean particle size typically about 0.1 inch but this depends upon the crushing process. The material generally has a very wide particle size distribution and often contains a high proportion of fines. The material reported here had a top size of 0.5 inch.

One of the pipelines through which this cryolite was conveyed is shown in Figure 12.13 for reference. It was two inch nominal bore, 165 feet in length and contained eleven 90° bends, each having a D/d ratio of about 6:1. The material was fed into the pipeline by means of a high pressure blow tank. Since the material had such a large mean particle size and contained large lumps, in addition to being very abrasive, a blow tank was an ideal feeder for the cryolite.

Conveying characteristics for this cryolite conveyed through the Figure 12.13 pipeline are presented in Figure 12.14. As expected, the material could only be conveyed in dilute phase suspension flow. Despite the large particles in the material, and a particle density of about 190 lb/ft³, the minimum conveying air velocity was about 2800 ft/min. This relatively low value of pick-up velocity, for such a material, is helped significantly by the fact that the material had a very wide particle size distribution and a large proportion of fines.

Pipeline:
- length = 165 ft
- bore = 2 in
- bends = 11 × 90°
- D/d = 6

Figure 12.13 Sketch of pipeline used for the high pressure conveying of cryolite.
As a consequence of the high conveying air velocities required for conveying, and the abrasive nature of the material, it is generally recommended that wear resistant pipeline should be specified for conveying pipelines. Either alloy cast iron or basalt lined pipe would be suggested. All bends in the pipeline would also have to be similarly reinforced, and possibly with alumina ceramic materials for the greater wear resistance required.

Straight pipeline is not generally as vulnerable to erosive wear as the bends in the pipeline, but when large particles have to be conveyed the problem is exacerbated. In being conveyed through a horizontal pipeline the gravitational force on large particles is such that they tend to ‘skip’ along the pipeline and so low angle impact of the particles against the pipeline occurs on a regular basis. This wear mechanism is considered in detail in Chapter 20.

This cryolite has also been conveyed through the Figure 7.13 pipeline, which is three inch nominal bore and 310 feet long. In order to convey the cryolite through this pipeline, with high pressure air, a free air flow rate of 600 ft³/min was provided, rather than the 400 ft³/min that was used for other materials that have been conveyed through this pipeline and reported here. The conveying characteristics are presented in Figure 12.15. With a pick-up velocity of 2800 ft/min, conveying was possible with air supply pressures up to 35 psig with 600 ft³/min of free air available.
Figure 12.15 Conveying characteristics for cryolite conveyed through the pipeline shown in Figure 7.13.

Figure 12.15 clearly shows the influence of free air flow rate on the conveying capability of dilute phase conveying systems. With only 400 ft$^3$/min the maximum value of air supply pressure that could be used would be about 20 psig, regardless of the fact that air was available at 100 psig. With only 200 ft$^3$/min almost nothing could be conveyed through the pipeline at all.

The conveying characteristics for calcined alumina conveyed through this same pipeline were presented earlier in Figure 12.7. With only 400 ft$^3$/min of free air available for conveying, but with a lower pick-up velocity of 2300 ft/min, air supply pressures up to about 25 psig could be employed. If the two sets of data are compared it will be seen that a maximum of about 27,000 lb/h of cryolite could be conveyed with a pressure drop of 25 lb/in$^2$, but only about 23,000 lb/h of calcined alumina could be conveyed with the same pressure drop.