1

Types of Pneumatic Conveying Systems

1 INTRODUCTION

Pneumatic conveying systems are basically quite simple and are eminently suitable for the transport of powdered and granular materials in factory, site and plant situations. The system requirements are a source of compressed gas, usually air, a feed device, a conveying pipeline and a receiver to disengage the conveyed material and carrier gas. The system is totally enclosed, and if it is required, the system can operate entirely without moving parts coming into contact with the conveyed material.

High, low or negative pressures can be used to convey materials. For hygroscopic materials dry air can be used, and for potentially explosive materials an inert gas such as nitrogen can be employed. A particular advantage is that materials can be fed into reception vessels maintained at a high pressure if required.

1.1 System Flexibility

With a suitable choice and arrangement of equipment, materials can be conveyed from a hopper or silo in one location to another location some distance away. Considerable flexibility in both plant layout and operation are possible, such that multiple point feeding can be made into a common line, and a single line can be discharged into a number of receiving hoppers. With vacuum systems, materials can be picked up from open storage or stockpiles, and they are ideal for clearing dust accumulations and spillages. Pipelines can run horizontally, as well as vertically.
up and down, and with bends in the pipeline any combination of orientations can be accommodated in a single pipeline run. Material flow rates can be controlled easily and monitored to continuously check input and output, and most systems can be arranged for completely automatic operation.

Pneumatic conveying systems are particularly versatile. A very wide range of materials can be handled and they are totally enclosed by the system and pipeline. This means that potentially hazardous materials can be conveyed quite safely. There is minimal risk of dust generation and so these systems generally meet the requirements of any local Health and Safety legislation with little or no difficulty.

Pneumatic conveying plants take up little floor space and the pipeline can be easily routed up walls, across roofs or even underground to avoid any existing equipment or structures. Pipe bends in the conveying line provide this flexibility, but they will add to the overall resistance of the pipeline. Bends can also add to problems of particle degradation if the conveyed material is friable, and suffer from erosive wear if the material is abrasive.

1.2 Industries and Materials

A wide variety of materials are handled in powdered and granular form, and a large number of different industries have processes that involve their transfer and storage. Some of the industries in which bulk materials are conveyed include agriculture, mining, chemical, pharmaceuticals, paint manufacture, and metal refining and processing. In agriculture very large tonnages of harvested materials such as grain and rice are handled, as well as processed materials such as animal feed pellets. Fertilizers represent a large allied industry with a wide variety of materials.

A vast range of food products from flour to sugar and tea to coffee are conveyed pneumatically in numerous manufacturing processes. Confectionery is an industry in which many of these materials are handled. In the oil industry fine powders such as barite, cement and bentonite are used for drilling purposes. In mining and quarrying, lump coal and crushed ores and minerals are conveyed. Pulverized coal and ash are both handled in very large quantities in thermal power plants for the generation of electricity.

In the chemical industries materials include soda ash, polyethylene, PVC and polypropylene in a wide variety of forms from fine powders to pellets. Sand is used in foundries and glass manufacture, and cement and alumina are other materials that are conveyed pneumatically in large tonnages in a number of different industries.

1.3 Mode of Conveying

Much confusion exists over how materials are conveyed through a pipeline and to the terminology given to the mode of flow. First it must be recognized that materials can either be conveyed in batches through a pipeline, or they can be conveyed on a continuous basis, 24 hours a day if necessary. In batch conveying the material may be conveyed as a single plug if the batch size is relatively small.
1.3.1 Dilute Phase

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 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 size, shape or density.

1.3.2 Dense Phase

In dense phase conveying two modes of flow are recognized. One is moving bed flow, in which 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.

1.3.3 Conveying Air Velocity

For dilute phase conveying a relatively high value of conveying air velocity must be maintained. This is typically in the region of 2400 ft/min for a very fine powder, 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 600 ft/min, and lower in certain circumstances. Because of the fine particle size required to provide the necessary air retention, particle density does not have such a significant effect on the minimum value of conveying air velocity in moving bed type dense phase conveying.

1.3.4 Solids Loading Ratio

The solids loading ratio, or phase density, is a useful parameter in helping to visualize the flow. This is the ratio of the mass flow rate of the material conveyed divided by the mass flow rate of the air used to convey the material. It is expressed in a dimensionless form. For dilute phase, maximum values that can be achieved are typically of the order of 15, although this can be higher if the conveying distance is short and the conveying line pressure drop is high.

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 10 lb/in$^2$ per 100 foot of horizontal pipeline. For plug type flows the use of solids loading ratio is not so appropriate, for as the materials have to be very permeable, maximum values are only of the order of about 30. Despite the low value of solids loading ratio, materials can be reliably conveyed at velocities of 600 ft/min and below in plug type flow.

Copyright © 2004 by Marcel Dekker, Inc. All Rights Reserved.
2 SYSTEM TYPES

A wide range of pneumatic conveying systems are available, and they are all generally suitable for the conveying of dry bulk particulate materials. The majority of systems are conventional, continuously operating, open systems, in a fixed location. To suit the material being conveyed, or the process, however, innovatory, batch operating and closed systems are commonly used. Many of these systems can be either positive or negative pressure in operation, or a combination of the two. In this review some of the more common systems are presented.

The problem of system selection is illustrated in Figure 1.1. This shows the combinations that are possible for conventional pneumatic conveying systems with a single air source. Only system types are presented in detail, with positive pressure, vacuum, and combined positive and negative pressure systems considered, in relation to both open and closed systems.

With such a wide range and choice of system types, a useful starting point is to consider the alternatives in pair groupings:

- **Open and closed systems**  Open systems are the norm for pneumatic conveying, particularly when conveying with air. Closed systems would only be employed for very specific circumstances, such as with highly toxic and potentially explosive materials.

- **Positive pressure and negative pressure systems**  Materials can be sucked as well as blown and so either pressure or vacuum can be employed for pneumatic conveying. This is often a matter of company or personal preference.

- **Fixed and mobile systems**  The majority of pneumatic conveying systems are in fixed locations and so this is not identified as a particular case. A variety of mobile systems are available for specific duties.

![Diagram](image)

**Figure 1.1** Diagram to illustrate the wide range of conveying systems available for conventional systems operating with a single air source.

---

Copyright © 2004 by Marcel Dekker, Inc. All Rights Reserved.
High and low pressure systems In pneumatic conveying, high pressure typically means any pressure above about 15 lbf/in$^2$ gauge. For systems delivering materials to reception points at atmospheric pressure, 100 lbf/in$^2$ gauge is typically the upper limit, due to the problems of air expansion. Very much higher pressures (typically 300 to 400 lbf/in$^2$) can be employed if delivering materials to reception points maintained at pressure, such as chemical reactors and fluidized bed combustion systems.

Conventional and innovatory systems Conventional systems are those in which the material is simply fed into a pipeline and either blown or sucked, and so this is not identified as a particular case since this is the norm. Innovatory systems are those in which the material to be conveyed is conditioned in some way, either at the feed point or along the length of the pipeline, generally in order to convey the material at low velocity and hence in dense phase, if the material has no natural capability for low velocity conveying.

Batch and continuously operating systems Both of these types of conveying are common in industry.

Single and multiple systems The majority of conveying systems are single units. It is possible, however, to combine units for certain duties.

Dilute and dense phase systems Dilute and dense phase conveying do not relate to any particular type of system. Any bulk particulate material can be conveyed in dilute phase. It is primarily the properties of the material that determine whether the material can be conveyed in dense phase, particularly in conventional conveying systems.

Pipeline and channel flow systems In the vast majority of pneumatic conveying systems the material is conveyed through pipelines. Fluidized motion conveying systems generally employ channels having a porous base, through which air is introduced, and they are very limited with regard to vertical conveying.

3 CLOSED SYSTEMS

For certain conveying duties it is necessary to convey the material in a controlled environment. If a dust cloud of the material is potentially explosive, nitrogen or some other gas can be used to convey the material. In an open system such environmental control can be very expensive, but in a closed system the gas can be re-circulated and so the operating costs, in terms of inert gas, are significantly reduced.

If the material to be handled is toxic or radioactive, it may be possible to use air for conveying, but very strict control would have to be maintained. A closed system would be essential in this case. Continuous conveying systems are probably the easiest to arrange in the form of a closed loop. A typical system is shown in Figure 1.2.
Chapter 1

Heat Exchanger
Supply Hopper
Blower
Back-up Filter
Primary Filter
Reception Hopper
Feeder

Figure 1.2 A closed loop pneumatic conveying system.

A null point needs to be established in the system where the pressure is effectively atmospheric and provision for make up of conveying gas can be established there. If this is positioned after the blower the conveying system can operate entirely under vacuum. If the null point is located before the blower it will operate as a positive pressure system.

A back-up filter would always be recommended, because positive displacement blowers and compressors are very vulnerable to damage by dust. This is simply a precaution against an element in the filter unit failing. There will generally be an increase in temperature across an air mover and so in a closed loop system it may be necessary to include a heat exchanger, otherwise there could be a gradual build up in temperature. The heat exchanger can be placed either before or after the air mover, depending upon the material being conveyed.

4 OPEN SYSTEMS

Where strict environmental control is not necessary an open system is generally preferred, since the capital cost of the plant will be less, the operational complexity will be reduced, and a much wider range of systems will be available. Most pneumatic conveying systems can ensure totally enclosed material conveying, and so with suitable gas-solid separation and venting, the vast majority of materials can be handled quite safely in an open system. Many potentially combustible materials are conveyed in open systems by incorporating necessary safety features.
4.1 Positive Pressure Systems

Although positive pressure conveying systems discharging to a reception point at atmospheric pressure are probably the most common of all pneumatic conveying systems, the feeding of a material into a pipeline in which there is air at a positive pressure does present a number of problems. A wide range of material feeding devices, however, are available that can be used with this type of system, from verturis and rotary valves to screws and blow tanks, and these are considered in detail in Chapter 2. A typical low positive pressure pneumatic conveying system is shown in Figure 1.3.

With the use of diverter valves, multiple delivery to a number of reception points can be arranged very easily with positive pressure systems. Although multiple point feeding into a common line can also be arranged, care must be taken, particularly in the case of rotary valve feeding of the pipeline, since air leakage through a number of such valves can be quite significant in relation to the total air requirements for conveying.

4.2 Negative Pressure (Vacuum) Systems

Negative pressure systems are commonly used for drawing materials from multiple sources to a single point. There is little or no pressure difference across the feeding device and so multiple point feeding into a common line presents few problems. As a result the rotary valve and screw can also be a much cheaper item for feeding a pipeline in a negative pressure system than in a positive pressure system. The filtration plant, however, has to be much larger as a higher volume of air has to be filtered under vacuum conditions. Particular care, therefore, must be taken when specifying these particular components. A typical system is shown in Figure 1.4.

![Figure 1.3](image.png)  
A typical positive pressure conveying system.

![Figure 1.4](image.png)  
A typical negative pressure conveying system.
Negative pressure systems are also widely used for drawing materials from open storage, where the top surface of the material is accessible. This is achieved by means of suction nozzles. Vacuum systems, therefore, can be used most effectively for off-loading ships. They are also particularly useful for cleaning processes, such as the removal of material spillages and dust accumulations. Another application is in venting dust extraction hoods.

If a very high vacuum is used for the conveying of a material, consideration should be given to the stepping of the pipeline part way along its length. Air is compressible and the rate of change of volume increases considerably with decrease in pressure. If the pipeline is not stepped, extremely high values of conveying air velocity can occur towards the end of the pipeline. The situation is the same for very high pressure positive pressure conveying systems. These issues are considered in detail in Chapters 5 and 9.

Vacuum systems have the particular advantage that all gas leakage is inward, so that the injection of dust into the atmosphere is virtually eliminated. This is particularly important for the handling of toxic and explosive materials, or any material where environmental considerations have to be taken into account. It is not always necessary to employ a closed system with these materials, therefore, provided that adequate safety measures are taken, particularly with regard to exhaust venting.

As a result of the conveying air being drawn through the air mover, it is essential that the exhauster should be protected from the possibility of the failure of one or more of the filter elements in the gas-solids separation system. This can be achieved by incorporating a back-up filter, as shown in Figure 1.2 for the closed loop system. A negative pressure conveying system operating with a vacuum nozzle is shown in Figure 1.5.
4.3 Combined Negative and Positive Pressure Systems

Protection has to be provided for the exhauster/blower from the possible ingress of material, as with negative pressure and closed loop systems. It should be noted that the available power for the system has to be shared between the two sections, and that the pipelines for the two parts of the system have to be carefully sized to take account of different operating pressures.

Some air movers, such as positive displacement blowers, operate on a given pressure ratio, and this will mean that the machine will not be capable of operating over the same pressure range with the combined duty as compared with their individual operation. This will mean that the system capability is limited in terms of both tonnage and distance. Although there is only one air mover, two filter units will be required. A typical system is shown in Figure 1.6.

Figure 1.5  Vacuum conveying from open storage.

Figure 1.6  Combined negative and positive pressure system.
4.4 Dual Vacuum and Positive Pressure Systems

If the conveying potential of a system requiring the vacuum pick-up of a material needs to be improved beyond that capable with a combined negative and positive pressure system, whether in terms of conveying distance or material conveying rate, then a dual system should be considered. In this combination the two conveying elements are separated and two air movers are provided.

A typical system is shown in Figure 1.7. It should be noted that as there are two separate systems, two gas-solid separation devices also have to be provided. Filters and valves have been omitted from the sketch of the system for clarity.

As two air movers are provided this means that the most suitable exhauster can be dedicated to the vacuum system and the most appropriate positive pressure system can be used for the onward transfer of material. If the vacuum off-loading section is only a short distance, it is possible that the material could be conveyed in dense phase over the entire conveying distance. It is simply a matter of pressure gradient for materials that have good air retention properties, as considered in Chapters 4 and 7.

The system shown in Figure 1.7 is typical of a ship off-loading system. With a high vacuum exhauster a material such as cement could be off-loaded at a rate of about 900 to 1000 ton/h through a single pipeline. Twin vessels on the quayside would allow continuous conveying to shore based reception vessels, which could be some 2000 ft distant if a high pressure compressor was to be used. For the onward conveying two pipelines would probably need to be used to achieve the 1000 ton/h.

Figure 1.7 Typical dual vacuum and positive pressure system.
5 BATCH CONVEYING

The systems considered so far have all been capable of continuous conveying. In many processes, however, it may be more convenient to convey one batch at a time. An additional classification of conveying systems, as indicated on Figure 1.1, is based on mode of operation. Conveying can either be carried out on a continuous basis or in a sequence of isolated batches.

Although a batch conveying system may be chosen for a specific process need, the mode of conveying is, to a large extent dictated by the choice of pipeline feeding device. The majority of batch conveying systems are based on blow tanks, and blow tanks are chosen either because of their high pressure conveying capability, or because of the abrasive nature of the material.

Two types of system are considered. In one, the batch size is relatively large, and the material is fed into the pipeline gradually, and so can be considered as a semi continuous system. In the other, the material is fed into the pipeline as a single plug. Particular features of blow tanks, as material feeding devices, are considered in Chapter 2. In this chapter the emphasis is on types of conveying system.

5.1 Semi Continuous Systems

It should be noted that when batches of material are fed into the pipeline gradually, there is essentially no difference in the nature of the gas-solids flow in the pipeline with respect to the mode of conveying through the pipeline. This is certainly the case during the steady state portion or the conveying cycle, regardless of the value of solids loading ratio.

The blow tanks used vary in size from a few cubic feet, to 1000 ft$^3$ or more, generally depending upon the material flow rate required as well as a need to maintain a reasonable frequency of blow tank cycling. The material can be conveyed in dilute or dense phase, depending upon the capability of the material, the pressure available and the conveying distance, as with continuously operating systems.

With a single blow tank it is not possible to utilize the pipeline while the blow tank is being filled with material or when the system is being pressurized. Since batch conveying is discontinuous, steady state values of material flow rate, achieved during conveying, have to be higher than those for continuously operating systems in order to achieve the same time averaged mean value of material flow rate. This means that air requirements and pipeline sizes have to be based on the maximum, or steady state, conveying rate. The intermittent nature of the conveying cycle is illustrated in Figure 1.8.

In comparison with a continuously operating system, therefore, the batch operating system would appear to be at a disadvantage. Blow tank systems, however, can operate at very much higher pressures to compensate, and they can be configured to operate continuously, as will be considered in the next chapter on pipeline feeding systems.
It should be emphasized that blow tanks can be operated at low as well as high pressure, depending upon the system needs. If a material needs to be fed into a chemical reactor or a boiler plant that is maintained at a pressure of 400 lbf/in$^2$, for example, the blow tank can be designed to operate at 410 lbf/in$^2$ for the duty. When delivering material to a reception point at atmospheric pressure, however, air supply pressures greater than about 100 lbf/in$^2$ are rarely used. This is mainly because of the problem of air expansion and the need for a stepped pipeline to prevent excessively high values of conveying air velocity.

A typical batch conveying system based on a single blow tank is illustrated in Figure 1.9.
5.2 Single Plug Systems

In the single plug conveying system the material is effectively extruded into the pipeline as a single plug, although the material is generally well aerated. It is typically about 30 ft long. This plug is then blown through the pipeline as a coherent plug. A certain amount of material will tail off the end of the plug as it is conveyed, but the front of the plug will sweep up material deposited in the pipeline by the previous plug. Blow tanks are generally used as the feeding device and a typical single plug conveying system is shown in Figure 1.10.

The air pressure has to overcome the frictional resistance of the plug of material in the pipeline. As a result blow tank sizes are rarely larger than 150 ft³, unless very large diameter pipelines are employed. In terms of system design, a cycling frequency is selected to achieve the required material flow rate, which determines the batch size. The pipe diameter is then selected such that the frictional resistance of the plug results in a reasonable air supply pressure to propel the plug at the given velocity.

The material will be conveyed at a low velocity, in what may be regarded as dense phase, but solids loading ratios have no significance here, and steady state conveying, as depicted on Figure 1.8 does not apply either. Single plug systems are capable of conveying a wide range of materials, and generally at much lower velocities than can be achieved in continuously operating systems. Many coarse, granular materials are either friable or abrasive and can only be conveyed in dilute phase with conventional conveying systems, and so single plug systems can represent a viable alternative, although it would always be recommended that tests be carried out to confirm this.

![Figure 1.10](image)

**Figure 1.10** Sketch of a typical single plug conveying system.
Material discharge often represents a problem with this type of system. Although the plugs of material are conveyed at a relatively low velocity, once they are discharged from the pipeline the high pressure air released behind the plug can cause severe erosion of the pipeline on venting.

6 INNOVATORY SYSTEMS

Unless the material to be conveyed has natural bulk characteristics such as good air retention or permeability, it is unlikely that it will be possible to convey the material at low velocity, and in dense phase, in a conventional continuous or semi continuous conveying system such as those described above. Even if a high pressure system is employed it is unlikely that such a material will convey in dense phase, unless the pipeline is relatively short. Dense phase conveying is not synonymous with high pressure, it is material property dependent.

For materials that are either abrasive or friable, alternatives to conventional systems may have to be considered, particularly if the materials are not capable of being conveyed in a dense phase mode, and hence at low velocity. For friable materials considerable particle degradation can occur in high velocity suspension flow, and erosion of bends in the pipeline and other plant surfaces subject to particle impact will occur if an abrasive material is conveyed in dilute phase suspension flow.

For a material that is only slightly hygroscopic, successful conveying may be achieved if the material is conveyed in dense phase, without the need for air drying equipment, since air quantities required for conveying can be significantly lower than those for dilute phase. For food products, that may be subject to a loss in flavor in contact with air, dense phase conveying might be recommended. If any such material is not capable of being conveyed in dense phase in conventional systems, however, alternative systems will also have to be considered.

With a need to convey many materials at low velocity, much development work has been undertaken since the late 1960's to find means of conveying materials with no natural dense phase conveying capability at low velocity. The innovatory systems produced as a result of these developments have centered around some form of conditioning of the conveyed material, either at the feed point into the pipeline or along the length of the pipeline. Since the modifications are essentially based on the pipeline, types of conveying system have not changed significantly.

6.1 Plug Forming Systems

The pulse phase system was developed in the late 1960's. A typical pulse phase system is shown in Figure 1.11. An air knife, positioned at the start of the pipeline, intermittently pulses air into the pipeline to divide the discharging material into discrete short plugs. Blow tanks are commonly used for the feeding of materials in this type of system also.
No further conditioning of the material occurs along the length of the pipeline. The pulse phase system was initially proposed as a solution to the problem of conveying cohesive bulk solids, but subsequent developments have shown that a wider range of materials can be conveyed successfully.

6.2 By-Pass Systems

The most common by-pass systems employ a small pipe running inside the conveying line, having fixed ports, or flutes, at regular intervals along its length. This inner pipe is not supplied with an external source of air, but air within the conveying line can enter freely through the regular openings provided. In an alternative design the by-pass pipe runs externally to the pipeline and is interconnected at regular intervals. By this means pipeline bends can also be conveniently incorporated.

If the material is impermeable the air will be forced to flow through the by-pass pipe if the pipeline blocks. Because the by-pass pipe has a much smaller diameter than the pipeline, the air will be forced back into the pipeline through the next and subsequent flutes because of the extremely high pressure gradient, and this will effect a break up of the plug of material causing the blockage.

6.3 Air Injection Systems

A number of systems have been developed that inject air into the pipeline at regular points along its length, as illustrated in Figure 1.12.
While by-pass pipe systems artificially create permeability in the bulk material, air injection will help to maintain a degree of air retention within the material. Continuous injection of air into the pipeline, however, does mean that conveying air velocities towards the end of the pipeline will be much higher as a result.

In some systems sensors are positioned between the parallel air line and the conveying pipeline and air is only injected when required. If a change in pressure difference between the two lines is detected, which would indicate that a plug is forming in the conveying pipeline, air is injected close to that point in order to break up the plug and so facilitate its movement. Various plug control systems, including both by-pass pipe and air addition methods are shown in Figure 1.12.

Many of the innovatory systems are capable of being stopped and re-started during operation. With most conventional systems this is not possible, and would result in considerable inconvenience in clearing pipelines if a blockage should occur as a consequence. Since they are capable of conveying materials in dense phase, operating costs for power are likely to be lower than those for a conventional dilute phase system. Capital costs for the innovatory systems are likely to be higher, however, and so an economic assessment of the alternative systems would need to be carried out.

7 FLUIDIZED MOTION CONVEYING SYSTEMS

The categorizing of fluidized motion conveying systems always represents a problem. They are not generally recognized as pneumatic conveying systems because
they only use very low positive pressure air, the material does not flow through a pipeline, and they have been limited to flow down gradual inclines only. They are, however, clearly not in the mechanical conveying group of conveyors. Until recent years their application was relatively limited because the main driving force was gravity, and so they would only operate on a downward incline, although at a very low angle.

The material is conveyed along a channel that has a continuous porous base. Air enters the material through the porous base and fluidizes the material. In this condition the material will behave like a liquid and flow down an inclined channel. The channel is generally closed to keep the system dust tight.

In early systems the channel ran with the material only partly filling the channel. The fluidizing air escaped into the space above the flowing material and was ducted to a filtration plant. In a recent development the channel operates full of material and is capable of running horizontally. It is possible that the channel could be made to operate at a higher pressure and so be able to convey material up an incline. As the channel can run full, negative pressure operation is another possibility.

### 7.1 Air-Assisted Gravity Conveyors

In situations where the flow of a material can be downwards, the air-assisted gravity conveyor has a number of advantages over pneumatic conveying systems. Plant capital costs can be much lower, operating costs are significantly lower, and a wide range of materials can be conveyed at a very low velocity.

Air-assisted gravity conveyors can be regarded as an extreme form of dense phase conveying. The conveyor consists essentially of a channel, divided longitudinally by means of a suitable porous membrane on which the material is conveyed. Such a system is shown in Figure 1.13.

![Figure 1.13 Air-assisted gravity conveyor.](image)
If a small quantity of low pressure air is fed through the membrane, the inter-particle and particle/wall contact forces will be reduced and the material will behave like a liquid. If a slight slope is imparted to the conveyor, the material will flow. These conveyors are often referred to as ‘air slides’. They have been in use for over 100 years and are still widely used today for materials such as alumina, cement and fly ash.

Air-gravity conveyors, ranging in width from 4 in to 2 ft, can convey materials over distances of up to 300 ft, and are suitable for material flow rates of up to about 3000 ton/h. In general, most materials in the mean particle size and density ranges from 40 to 500 micron and 80 to 300 lb/ft$^3$ are the easiest to convey and will flow very well down shallow slopes.

### 7.2 Full Channel Conveyors

Hanrot [1] describes a pressurized horizontal conveying system developed by Aluminum Pechiney to convey alumina. The alumina was conveyed from a single supply point to more than one hundred outlets. Electrolysis pots on a modern aluminum smelter were required to be filled and the distance from the silo to the furthest outlet was approximately 600 ft. Air at a pressure of about $1\frac{1}{2}$ lb/in$^2$ gauge is required. A conveying channel is employed, as with the air-assisted gravity conveyor, but the channel runs full of material. The system is illustrated in Figure 1.14 and this shows the principle of operation.

![Figure 1.14 Principle of potential fluidization ducts.](image-url)
Balancing columns are positioned on the conveying duct and are used for de-dusting. This is not a continuously operating system in the application described. It is a batch type system and its object is to meet the demands of the intermittent filling of the pot hoppers. The system, however, is clearly capable of continuous operation and of significant further development.

8 MOBILE SYSTEMS

All of the systems described so far have been essentially fixed systems. The only real flexibility in any of the systems has been the capability of moving vacuum nozzles in negative pressure systems. By the use of flexible hoses these can be moved, and they find wide application in ship off-loading systems, and the clearing of material from stockpiles or spillages. Many road sweeping vehicles employ vacuum conveying for their operation.

Many bulk particulate materials are transported from one location to another by road, rail and sea. Many materials, of course, are transported in a pre-packaged form, or in bulk containers, and can be transported by road, rail, sea or air, in a similar manner to any other commodity. Many transport systems, however, are specifically designed for bulk particulate materials and have a capability of self loading, self off-loading, or both. These are generally mobile versions of the above static conveying systems, depending upon the application and duty.

8.1 Road Vehicles

Road vehicles are widely used for the transport of a multitude of bulk particulate materials, such as cement, flour, sugar and polyethylene. Road vehicles often have their own positive displacement blower mounted behind the cab and so can off-load their materials independently of delivery depot facilities. The material containing element on the truck can generally be tipped to facilitate discharge, which can be via a rotary valve, or the container might double as a blow tank which can be pressurized.

8.2 Rail Vehicles

Rail cars or wagons generally rely on delivery depot facilities for off-loading. Because of their length tilting is not an option and so multiple point off-loading is often employed. They may be off-loaded by rotary valve, or the rail car may be capable of being pressurized so that it can be off-loaded as a blow tank.

Whereas road vehicles are typically designed to operate with air at 15 lbf/in² gauge for this purpose, rail vehicles are generally designed to 30 lbf/in² and can usually be off-loaded in about one hour. The base of the rail car is usually angled at about five degrees in herringbone fashion around each discharge point and fluidized to facilitate removal of as much material as possible.
8.3 Ships

Large bulk carriers usually rely on port facilities for off-loading and these are generally similar to that depicted in Figure 1.7. Intermediate bulk carriers, however, often have on-board facilities for off-loading. Such vessels are often used for the transfer of materials such as cement to storage depots at ports for local supply, or to off-shore oil rigs.

Materials are typically transferred from storage holds in the ship by a combination of air-assisted gravity conveyors and vacuum conveying systems, into twin blow tanks. High pressure air is supplied by on-board diesel driven compressors and materials are conveyed to dock-side storage facilities through flexible rubber hose, which solves the problems of both location and tidal movements.

9 MULTIPLE SYSTEMS

Two multiple systems have already been considered. These were the combined negative and positive pressure system, illustrated in Figure 1.6, and the dual vacuum and positive pressure system, illustrated in Figure 1.7. A third possibility is the staging of pneumatic conveying systems, which would be required for very long distance conveying. Materials are currently conveyed over distances of 5000 ft in a single stage and flow rates of 40 ton/h over this distance are not unusual.

With much higher air supply pressures, conveying over longer distances is possible, and with larger bore pipelines higher material flow rates can be achieved. For very much longer distance conveying, however, staging will have to be employed. A problem with using very high pressure air is that of the expansion of the air and the need to step the pipeline to a larger bore part way along its length, but this can be overcome to a large extent by discharging the material at the end of each stage at a pressure of about 45 lbf/in² rather than to atmospheric pressure.

10 SYSTEM REQUIREMENTS

The uses, applications and requirements of pneumatic conveying systems are many and varied. A number of system requirements were highlighted at various points with regard to the systems. Some of the more common requirements of systems can be identified and are detailed here for easy access and reference, since these may feature prominently in the choice of a particular system.

10.1 Multiple Pick-Up

If multiple point feeding into a common line is required, a vacuum system would generally be recommended. Although positive pressure systems could be used, air leakage across feeding devices such as rotary valves represents a major problem. The air leakage from a number of feed points would also result in a significant

Copyright © 2004 by Marcel Dekker, Inc. All Rights Reserved.
energy loss. The air loss could be overcome by adding isolation valves to each feed point, but this would add to the cost and complexity of the system.

10.2 Multiple Delivery

Multiple delivery to a number of reception points can easily be arranged with positive pressure systems. Diverter valves can be used most conveniently for this purpose. Such a system was illustrated in Figure 1.3. This shows a separate filter unit mounted on each reception hopper. If the situation allows, a common unit could be used, but care would have to be taken with the specification and layout.

The problem with vacuum systems performing this function is equivalent to the problem of using a positive pressure system for the multiple pick-up of materials, which is one of multiple point air leakage. In this case, however, it is ingress of air into the system. Any air leaking into a conveying system pipeline along its length will by-pass the material feed point and this could result in the conveying air velocity being too low to convey the material.

10.3 Multiple Pick-Up and Delivery

The suck-blow, or combined vacuum and positive pressure system, illustrated in Figure 1.6 is ideal for situations where both multiple pick-up and delivery is required. The pressure drop available for conveying is rather limited with this type of system and so if it is necessary to convey over a long distance, a dual system would be more appropriate. In this the vacuum and positive pressure conveying functions are separated and a high pressure system can be used to achieve the distant conveying requirement, as shown in Figure 1.7.

10.4 Multiple Material Handling

If it is required to handle two or more materials with the one system, reference should be made to the conveying characteristics for each material to be conveyed. It is quite likely that the air requirements for the materials will differ to a large extent, and that different flow rates will be achieved for each material, for identical conveying conditions.

In this case it will be necessary to base the air requirements, to be specified for the air mover, on the material requiring the highest conveying line inlet air velocity. Consideration will then have to be given to a means of controlling the air flow rate, to lower values, for the other materials, if this should be required. Alternatively the same air flow rate can be used for each material but different pipeline bores will have to be used to achieve the conveying air velocity values required.

Since it is likely that the flow rate of each material will be different, the feeding device, or devices, will have to meet the needs of every material, in terms of flow rate and control. The solutions will also differ between a system in which there is a change of material to be conveyed, and a system in which different materials are to be fed from one or a number of different supply hoppers.
10.5 Multiple Distance Conveying

If it is required to convey a material over a range of distances, such as a road tanker supplying a number of different installations, or a pipeline supplying a number of widely spaced reception points, consideration will again have to be given to differing material flow rates and air requirements. It is possible for both of these to change if there is a change in conveying distance, for whatever reason.

For a given air supply, in terms of delivery pressure and volumetric flow rate, the material flow rate achieved will decrease with increase in conveying distance. As a consequence the material feeding device will either need to be controlled to meet the variation in conveying capability, or the feed rate will have to be set to the lowest value for the longest distance.

For materials capable of being conveyed in dense phase there is the added problem of the possibility that the air flow rate will also need to be increased if there is a significant change in conveying distance.

10.6 Conveying From Stockpiles

If the material is to be conveyed from a stockpile, then a vacuum system using suction nozzles will be ideal. The type of system required will depend upon the application and conveying distance. For a short distance a vacuum system will probably meet the demand on its own.

Where access is available to a free surface, as in ship off-loading, vacuum nozzles can transfer material under vacuum to a surge hopper. If this is not the final destination for the material it could be the intermediate hopper in a combined positive and negative pressure conveying system, or the supply hopper for the second part of a dual system, from where the material could be blown onward.

For clearing dust accumulations and spillages, and surplus material deposited in stockpiles, mobile units are particularly useful. These are generally suck-blow systems with a vacuum nozzle. Although they can be small versions of a continuously operating suck-blow system, they are more usually batch conveying systems with the transfer hopper acting also as a blow tank. Material is first drawn into the hopper/blow tank under vacuum, and when it is full it is pressurized and conveyed on to the reception point.

10.7 Start-Up With Full Pipeline

If there is likely to be a need to stop and start the conveying system while it is conveying material, a system capable of doing this will need to be selected. This is rarely possible in conventional systems, and so consideration will have to be given to innovatory systems.

Many of these systems are capable of starting with a full pipeline, although their capabilities on vertical sections may need to be checked, particularly if the stoppage is for a long period. The possibility of power cuts, from whatever source, should also be taken into account here.
11 MATERIAL PROPERTY INFLUENCES

The properties of the materials to be conveyed feature prominently in the decisions to be made with regard to the selection of a pneumatic conveying system. As with ‘System Requirements’, considered above, some of the more common material properties can be identified and are detailed here for easy access and reference.

11.1 Cohesive

Problems may be experienced with cohesive materials in hopper discharge, pipeline feeding and conveying. If there is any difficulty in discharging a cohesive material from a rotary valve, a blow-through type should be used. If there is any difficulty in conveying a cohesive material in a conventional system, then an innovatory system should be considered. The pulse phase system, for example, was developed for the handling of such fine cohesive powders.

11.2 Combustible

There is a wide range of materials which, in a finely divided state, dispersed in air, will propagate a flame through the suspension if ignited. These materials include foodstuffs such as sugar, flour and cocoa, synthetic materials such as plastics, chemical and pharmaceutical materials, metal powders, and fuels such as wood and coal. If a closed system is used the oxygen level of the conveying air can be controlled to an acceptable level, or nitrogen can be used. If an open system is to be used, then adequate safety devices must be put in place. One possibility is to use a suppressant system. Another is to employ pressure relief vents and other safety features.

11.3 Damp or Wet

Materials containing a high level of moisture can generally be conveyed in conventional systems if they can be fed into the pipeline, and do not contain too many fines. Most of the handling problems with wet materials occur in trying to discharge them from hoppers. Fine materials may not discharge satisfactorily from a conventional rotary valve and so a blow through type should be used.

Fine materials which are wet will tend to coat the pipeline and bends, and gradually block the line. Lump coal having a large proportion of fines is a particular problem in this respect. Single plug blow tank systems and some of the innovatory systems are capable of handling this type of material. If a conventional system must be used, the problem can be relieved by heating the conveying air, if the material is not too wet.

11.4 Electrostatic

If the build up of electrostatic charge is a problem when conveying a material, the air can be humidified. This process can be carried out on-line and does not usually
require a closed system. In dense phase the quantity of air which needs to be conditioned is much less than in dilute phase systems, and so for materials capable of being conveyed in dense phase, the operating costs for air quality control will be lower. The entire system and pipe-work network should be earthed.

11.5 Erosive

If the hardness of the particles to be conveyed is higher than that of the system components, such as feeders and pipeline bends, then erosive wear will occur at all surfaces against which the particles impact. Velocity is one of the major parameters and so the problem will be significantly reduced in a low velocity system. If a dilute phase system must be used, feeding devices with moving parts, such as rotary valves and screws, should be avoided, and all pipeline bends should be protected.

11.6 Friable

If degradation of the conveyed material is to be avoided, a system in which the material can be conveyed at low velocity should be considered. The magnitude of particle impacts, particularly against bends in the pipeline, should be reduced as this is one of the major causes of the problem. Damage caused by attrition as a consequence of particle to particle and particle to wall surfaces must also be taken into account. Pipeline feeding devices which can cause particle breakage, such as screws, should also be avoided.

11.7 Granular

Granular materials can be conveyed with few problems in pneumatic conveying systems provided that they can be fed into the pipeline. Problems with feeding can occur with top discharge blow tanks and conventional rotary valves. Air will often permeate through granular materials in top discharge blow tanks and the materials will not convey, particularly if the blow tank does not have a discharge valve. Granular materials containing a large percentage of fines, and which are not capable of dense phase conveying, may block in a top discharge line. In rotary valves, shearing of granular materials should be avoided, and so a valve with an off-set inlet should be used.

11.8 Hygroscopic

If a material is hygroscopic the air used for conveying can be dried to reduce the moisture level to an acceptable level. This process can be carried out on-line and does not usually require a closed system. For a material which is only slightly hygroscopic, successful conveying may be achieved if the material is conveyed in dense phase, without the need for air drying equipment, since air quantities required for conveying can be significantly lower than those for dilute phase conveying.
11.9 Low Melting Point

The energy from the impact of particles against bends and pipe walls at high velocity in dilute phase conveying can result in high particle temperatures being generated. The effect is localized to the small area around the point of contact on the particle surface, but can result in that part of the particle melting. The problem is accentuated if the particles slide on the pipe wall and around pipeline bends. Plastic pellets such as nylon, polyethylene and polyesters are prone to melting when conveyed in suspension flow.

Velocity is a major variable and so the problem will generally be significantly reduced for most materials in a low velocity, dense phase system. If such materials have to be conveyed in dilute phase a roughened pipeline surface may help to reduce the problem considerably as this will prevent the particles from sliding.

11.10 Radioactive

Radioactive materials must be conveyed under conditions of absolute safety, and so it would be essential to employ a closed system so that strict control of the conveying environment could be maintained. A vacuum system would also be necessary to ensure that no conveying air could escape from the system, or material in the event of a bend eroding, for some of these materials do tend to be rather abrasive.

11.11 Toxic

If toxic materials are to be handled, strict control of the working environment must be maintained. A vacuum system, therefore, would be essential to ensure that there could be no possibility of material leakage. If the conveying air, after filtration, could be vented safely to the atmosphere, an open system would be satisfactory. If not, a closed loop system would have to be used.

11.12 Very Fine

A problem of pipeline coating can occur with very fine powders in the low micron and sub-micron range, such as carbon black and titanium dioxide. These materials tend to adhere to the pipe wall when conveyed in conventional systems. The coating gradually builds up and can cause a marked reduction in the pipe section area, and hence a reduction in conveying capacity. Many of the innovatory systems are capable of handling this type of material successfully.

If a conventional system is to be used the material should be conveyed through a flexible pipeline or hose so that the material build-up can be shaken free on a regular basis. It is quite likely that the natural pulsations that occur within the system would be sufficient to vibrate the material free to enable it to be reentrained in the conveying line.
REFERENCES