Pneumatic Conveying of Bulk Solids Through Pipelines

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Summary

The article describes pneumatic conveying in pipelines, and the known systems, their applications, their possibilities and their limitations are briefly discussed. The aim has been to provide the plant constructor with decision criteria as an aid in choosing the right system for his purpose.

1. Introduction

This article describes the pneumatic conveying of powdered and granular solids through pipeline systems. Other means of pneumatic conveying, such as airtube mail transport systems or air slide systems, or conveying systems in which large items are moved on air cushions, will not be discussed here.

Pneumatic conveying is more of an art and not so much an engineering science, as one expert has put it. This still applies today in our age of space travel and microprocessors. All over the world theoretical studies have been made and published by many able engineers and scientists, and have been confirmed in practical tests, but the big specialist firms everywhere continue to work on the basis of their own "home-made recipes" which have come about in the most diverse ways. In general, these satisfy practical requirements very well since they are mostly simple and give usable results under the circumstances of everyday practice. But where conditions deviate from the norm, complicated tests are often required to confirm the calculations.

There are many reasons for this. In the pneumatic conveying of solids by means of a carrier gas, which is usually air, CO_2 or an inert gas, we are dealing with a two-component mixture. The small diagram (Fig. 1) explains the principle of pneumatic conveying. A certain minimum gas velocity is necessary for conveying, and this minimum velocity depends on the condition of the carrier gas and on the physical characteristics of the material to be conveyed. It can be seen from the diagram that the material does not move when the air velocity is low, but there is a velocity at which the material starts to be entrained. This is generally referred to as the choke point.

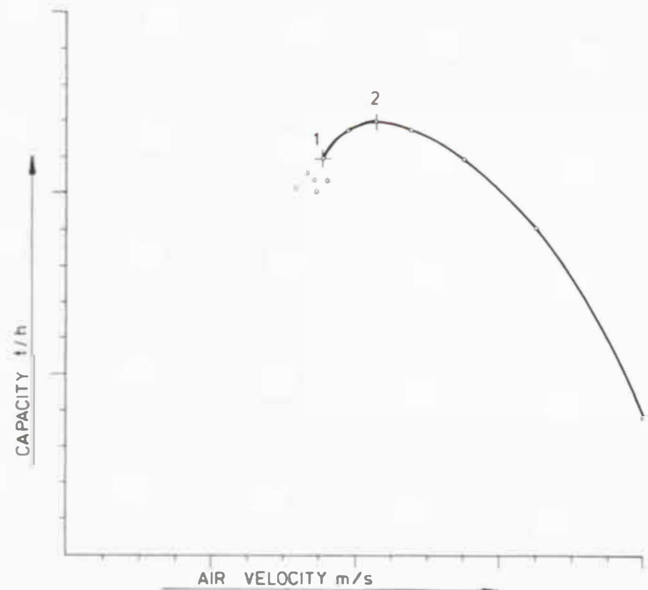

Fig. 1: Conveying capacity as a function of air velocity
1 start of conveyance, also choke point
2 optimum

The system is unstable at this velocity, i. e., the smallest drop in velocity will cause the material to settle out and so choke the pipeline. The designer accordingly chooses suitably higher velocities, which are then regarded as the optimum. A further increase in the air velocity and hence in the air volume would only cause an increase in pipeline resistance, the increase being proportional to the square of the air velocity. But if the available pressure is held constant, increasing conveying pressure means a drop in the rate of flow. The region below the already defined choke point has, however, been utilized for pneumatic conveying in the last two decades. This is the so-called plug-type conveying.

As everyone knows, gases are compressible. In this respect, therefore, they behave quite differently from liquids, which are used in hydraulic conveying. Owing to the friction losses in the pipelines (resistance to flow), the carrier gas has a different condition at every point in the pipeline. Also the specific loading, i. e., the weight of solids per cubic metre of carrier gas at OTP, changes constantly. This also causes changes in the gas and product velocities. The consequences of this have been the subject of many publications and will not be discussed here.

A further important ground for the scope for variation in designing pneumatic conveying systems lies in the nature of the product to be transported. Some of the main criteria are:

- type of material
- its specific gravity
- its elasticity
- its grain size
- its grain shape
- its grain size distribution, e. g., slope of RRS characteristic, etc.

Two salient examples are given here of the surprises which even experts can encounter. In the pneumatic conveying of alumina (Al_2O_3) it was found that one type (sandy) requires about 60% more air (60% higher starting velocity) than another (floury) type. The two types did not differ much in their physical data, only the grain shape was different. In the usual investigations this difference is not recognized, since normally only bulk density and screen analysis are determined.

In the other example, two PVC powders with very similar physical properties gave — in the same conveyor system — conveying capacities which varied in the ratio of about 1 : 2, i. e., with the same pipeline, the same air quantity and the same pressure.

2. Modes of Pneumatic Conveying

In general there are two basic types: vacuum conveying systems and pressure conveying systems. These differ in principle as follows:

Vacuum conveying systems

In these types the material to be conveyed is mixed with air (Fig. 2) under atmospheric conditions, i. e., the material is metered into the air stream and thence conveyed to a recipient. In overcoming the resistance to flow of the pipeline a negative pressure or vacuum develops along the route. Having arrived at the recipient, the solids and the air are separated from each other, and a compressor raises the pressure of the conveying air back to atmospheric. The material is removed from the system vacuum to atmosphere by way of an airlock. As may be seen, airlock and compressor are at the end of the conveying line.

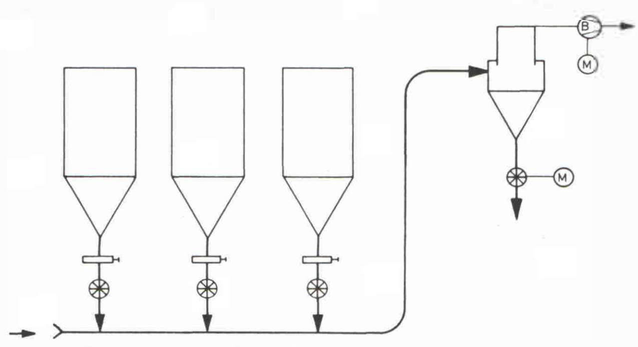

Fig. 2: Vacuum conveying system

Pressure conveying systems

The material to be conveyed is fed into the pipeline (Fig. 3) through an airlock. During the conveying operation the pipeline is under positive pressure. Downstream from the airlock the mixing of the material and the compressed air takes place. The conveying air is compressed in a compressor and transports the material to one or more receiving stations. These stations are usually silos or tanks. Air and material are there largely separated by gravity or by centrifugal force. Subsequent cleaning of the air in a filter is usual. It can be seen that with pressure conveying the airlock and the compressor are located at the start of the system.

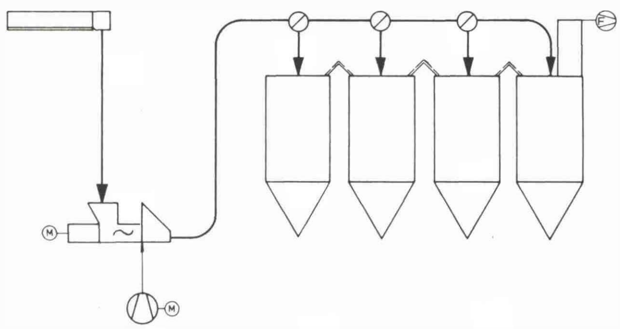

Fig. 3: Pressure conveying system

Choice of conveying system

Whoever has been faced with this choice knows that there is a great variety of conveying systems, but here also the engineering maxim applies that for each case there is only one best system. The various systems will be described here, keeping to the chosen division between vacuum systems and pressure systems.

2.1 Vacuum Conveying Systems

Vacuum systems have only a limited scope of application, but in spite of this they are — because so practical in use — "overproportionally often" encountered (Fig. 4).

Consideration of the diagram clearly shows why the scope of application of the vacuum system is so limited. Many small systems work with fans in the pressure range of about 100 mbar. Unlike the pressure system, the technically usable conveying line resistance is limited to about 0.5 bar (= 500 mbar). The reason for this can be seen from the diagram. With a negative pressure of 500 mbar the volume of conveying air is doubled at the end of the system, which means that compressor and filter must be designed for twice the effective air quantity. But if the line resistance is 750 mbar, compressor and filter must be designed to handle four times the effective air quantity.

This circumstance places a limit on the capacity and conveying distance of vacuum systems. In general, the following (simplified) formula applies to all pneumatic conveying systems, whether of the vacuum or pressure type. Assuming the same conveying line resistance, we have:

Conveying rate × distance = constant, or $t/h \times m = c$ (Fig. 5)

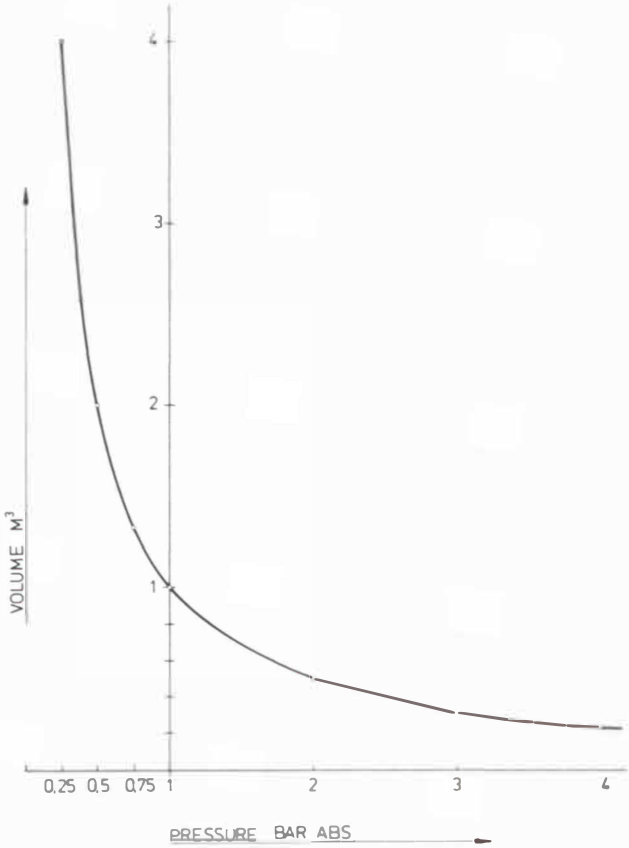

Fig. 4: Air volume as a function of pressure (bar abs)

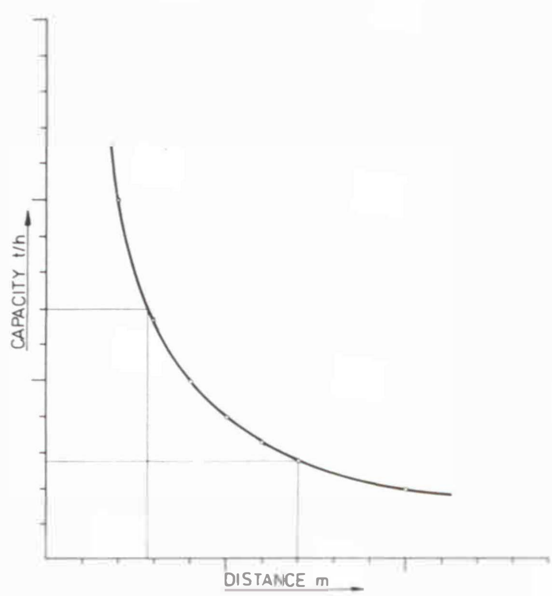

Fig. 5: Conveying capacity as a function of conveying distance at constant pressure

In a system based on the same pressure difference, we can either transport 50 t/h material over 20 metres or 20 t/h over 50 m, or 10 t/h over 100 m. But since other influencing factors come into play we cannot carry the analogy to the end points of the hyperbola, e. g., one metre or 2000 m conveying distance. The size of the air lock must also be considered of course. Even so, the formula gives important pointers for the design of a system. As soon as we have one point on the hyperbola of rate times distance, the rate for other distance can be calculated with sufficient accuracy for practical applications.

2.2 Pressure Conveying Systems

Pressure systems do not have such narrow limits in respect of conveying line pressure. Limitations and also classification stem only from the type and design of the airlocks and the compressors. Line pressures of up to 25 bar have already been employed for certain specialized plants.

These systems are most conveniently classified as low-pressure, medium-pressure and high-pressure depending on the type of compressor used. Thus:

— low-pressure systems with fans, pressure range about 100 mbar

— medium-pressure systems with roots type blowers and multi-stage fans, pressure range 0.5 to 1 bar

— high-pressure systems, with single-stage compressors up to 2.5 or 3 bar; multi-stage compressors up to 6, 8 or 10 bar.

Pneumatic conveying systems can also be classified on the basis of specific loading, i.e., kilograms of material conveyed per kilogram of air, or per cubic metre air at NTP or — which best complies with practical needs — kilograms of material per cubic metre of air at OTP. This is interesting enough, but for the practical man the classification as low-, medium- or high-pressure is the most suitable.

A relationship exists of course between specific loading and the resistance of the conveying line. Thus the low-pressure systems are dilute-phase systems, where the loading is usually about 1 kg/m³ although greater loadings of up to about 5 kg/m³ are possible. In such systems the air velocity may be 25 m/sec and more, depending on the type of material, and the material particles literally fly through the pipeline.

Medium-pressure systems lie between dilute-phase and dense-phase installations. The specific loading is about 5 to 15 kg/m³ depending on product and distance conveyed. These systems also are usually of the "flying particle" variety. Both powdered and granular materials can be transported.

With high-pressure systems the loading is about 10 to 50 kg/m³ and more, depending on product and distance. These are therefore dense-phase systems employed usually for dusts, etc.

In vertical lines there is a roughly uniform distribution of solids and carrier gas. In horizontal lines the picture is somewhat as follows (Fig. 6):

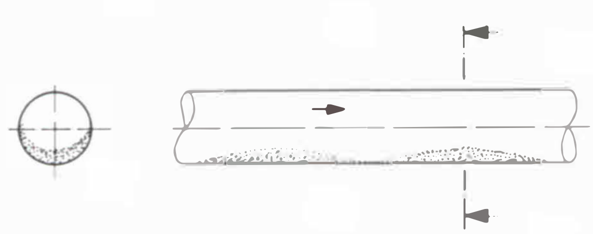

Fig. 6: Drifting of conveying product in conveying line

The mass of the material is on the bottom of the horizontal pipe and fills it to a depth of about one-quarter to one-third. This material flows with a wave-like movement along the pipe, it is said to drift. One can clearly hear the wave crests in the conveying system when a steel tank and not a concrete silo is being filled. The waves of material, of course, move much more slowly than the conveying air. The velocity of the latter (depending on the pressure) is between 5 and 10 m/sec. at the start of the line and about 20 to 30 or 40 m/sec at the end.

A special category of high-pressure conveying is plug-type or plugged-phase conveying with its variations. Individual plugs of material — introduced into the system through a pressure vessel — between which is the conveying air, are forced along through the pipeline. Greatly simplified, one could call it parcel transport by airtube without the packaging. Specific loading is very high and can amount to 400 kg/m³. The air velocity is very low. This mode of transport is used not only for powdered materials but also for granulates (e. g., in the plastics industry). The low air velocity is specially advantageous. With some granulated thermoplastics, threads — called sauerkraut or streamers — form under the influence of the otherwise necessary high velocities. With the low velocities employed with plugged-phase conveying, streamers do not occur, or only to a minimal extent.

The limits with respect to specific loading and classification are not clear cut, and depend to a great extent on the transportation distance, on the selected pipe diameter and on the product. For this reason we have here chosen the designations of low, medium and high pressure, which meet the practical requirements on the basis of the compressor types available.

3. Brief Specifications of Various Pneumatic Pipeline Conveying Systems

3.1 Vacuum conveying systems

3.1.1 Low-pressure system

a) Pressure range:	0.1 bar
b) Distance:	short to approx. max. 100 m
c) Compressor:	single-stage fan
d) Airlock:	rotary-vane feeder; power-actuated gate lock for abrasive materials
e) Material conveyed:	powders and granulates
f) Capacity:	from a few kg/h to 1000 kg/h, sometimes more
g) Remarks:	Used for small conveying capacities and short distances. Advantage is dust-free or low-dust operation if conveying air is also used for dust removal at material inlet. Mobile and stationary dust collector systems.

3.1.2 Medium-pressure system

a) Pressure range:	approx. 0.5 bar
b) Distance:	max. 100 m
c) Compressor:	Roots blower in most cases
d) Airlock:	rotary type vane feeder, gate locks, but also constant-head air locks for powdered materials in which the material acts as a barrier layer.
e) Material conveyed:	powders and granulates
f) Capacity:	up to 600 t/h and beyond
g) Remarks:	The best-known and most impressive examples of this type of vacuum conveying system are the large ship-discharging plants for grain, alumina and cement. Even before the first World War plants were built which could handle more than 100 t/h of grain. Piston pumps were used then, these often being direct-driven by a steam engine. These piston machines proved to be remarkably robust, since only cyclones were used to separate material and conveying air, so that the pumps had to "swallow" great amounts of dust. Even in those days they worked with vacuums of about 420 mbar (= 0.58 bar abs.). It would certainly have been simple to pull larger vacuums with the big piston pumps, but it was quickly discovered that the useful life of air locks is greatly shortened with larger vacuums.

3.2 Pressure conveying systems

3.2.1 Low-pressure system

a) Pressure range:	up to approx. 100 mbar
b) Distance:	up to about 100 m
c) Compressor:	fan
d) Airlock:	rotary vane feeder; also power-actuated two-stage gate lock when abrasive materials are to be handled.
e) Material conveyed:	powdered goods and granulates
f) Capacity:	from a few kg to several t/h. Used in the plastics, food and animal-feed industries.

3.2.2 Medium-pressure system

a) Pressure range:	lower: to 0.5 bar, higher: 0.8 to 1 bar
b) Distance:	up to about 150 m
c) Compressor:	Roots type blower
d) Airlock:	rotary-vane feeder for up to about 0.5 bar; power-actuated two-stage gate lock for abrasive materials, also for pressures above 0.5 bar; screw pump.
e) Material conveyed:	powdered goods and granulates
f) Capacity:	Usually up to about 5 t/h, but also higher. Used in the chemical, food and animal feed industries, but also in the cement industry; in the lower pressure range for transporting

filter dust, in the higher range for transporting pulverized coal (for firing rotary kilns and suspension-type preheaters). The very widely used form of medium-pressure conveying with rotary-vane feeder (with which roots type blowers are generally used), was formerly limited to pressures up to 0.5 bar. In recent years, however, roots type blowers have been further developed and there are now types on the market with which pressures of 1 bar can be attained. At such pressures, rotary-vane feeders are no longer recommended owing to the air-pressure impact, which increases with the pressure, and also because of the greatly increased wear. Use is then made of screw pumps.

3.2.2.1 Air-Lift (pneumatic elevator) (Fig. 7)
for vertical transport only.

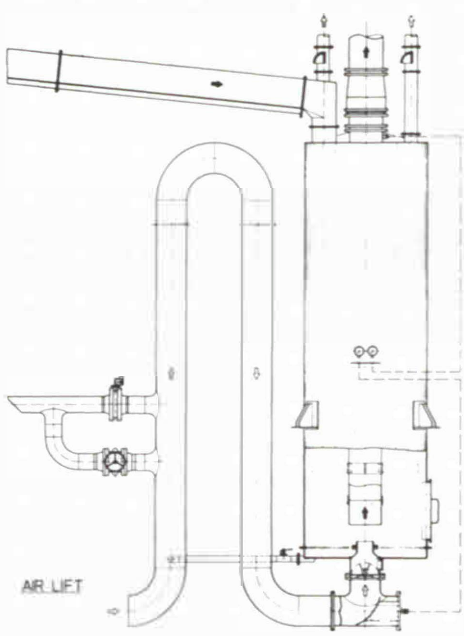

Fig. 7: Air lift

a) Pressure range: up to 0.8 bar (1.0 bar)
b) Distance: up to about 100 m
c) Compressor: roots type blower
d) Airlock: air lift tank
e) Material conveyed: powdered materials
f) Capacity: up to 500 t/h and beyond
g) Remarks: Air-lifts have won a secure place in the cement industry, for the charging of silos and also for preheaters. Since they have no moving parts they seldom give trouble. The powdered material is forced into the pipeline by the column of material in the tank and is there mixed with the conveying air. The necessary height of the tank depends on the conveying distance and on the diameter of the pipeline. If less material is fed to the air-lift, the level of material in the tank will drop accordingly. Air-lifts are only suitable for vertical movement of materials; horizontal transportation is not possible. In a horizontal pipe the material would settle out as described earlier, and the resultant pressures and pressure fluctuation could not be overcome with an air-lift system.

3.2.2.2 Jet Conveyor (Fig. 8)

a) Pressure range: 0.8 bar (1 bar)
b) Distance: up to about 50 m
c) Compressor: roots type blower (screw compressor)
d) Airlock: injector
e) Material conveyed: mainly powdered materials, sometimes also granulates
f) Capacity: up to 5 t/h and beyond
g) Remarks: The nozzle and diffuser of the jet conveyor produce an entrainment effect. About 20% of the initial pressure is converted to useful conveying-line pressure. The jet conveyor has no moving parts and is therefore specially suitable for handling abrasive materials such as fly ash. The fact that it is an uneconomical conveyor is put up with because of the fact that it is reliable, needs very little maintenance and is hardly subject to wear.

3.3 Continuous high-pressure conveying (Fig. 9)

3.3.1 Screw Pumps

a) Pressure range: 1.5 to 2.5 bar, depending on type
b) Distance: up to about 1000 m
c) Compressor: screw compressors, rotary compressors
d) Airlock: screw pump
e) Material conveyed: powdered materials
f) Capacity: up to 300 t/h and beyond
g) Remarks: Screw pump were developed in the USA at about the beginning of the 1920s. A high-speed screw, running at about 1000 rpm (on 50 Hz) or 1200 rpm on 60 Hz, receives the powdered material under atmospheric conditions and forces it into the pipeline, which is under pressure. These screws were orginally supported at each end. At the exit

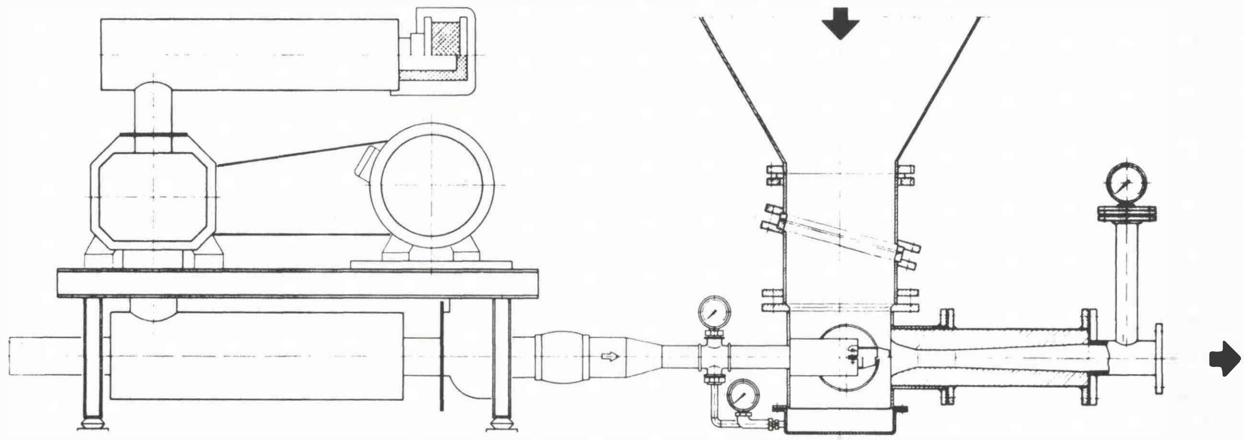

Fig. 8: Jet conveyor

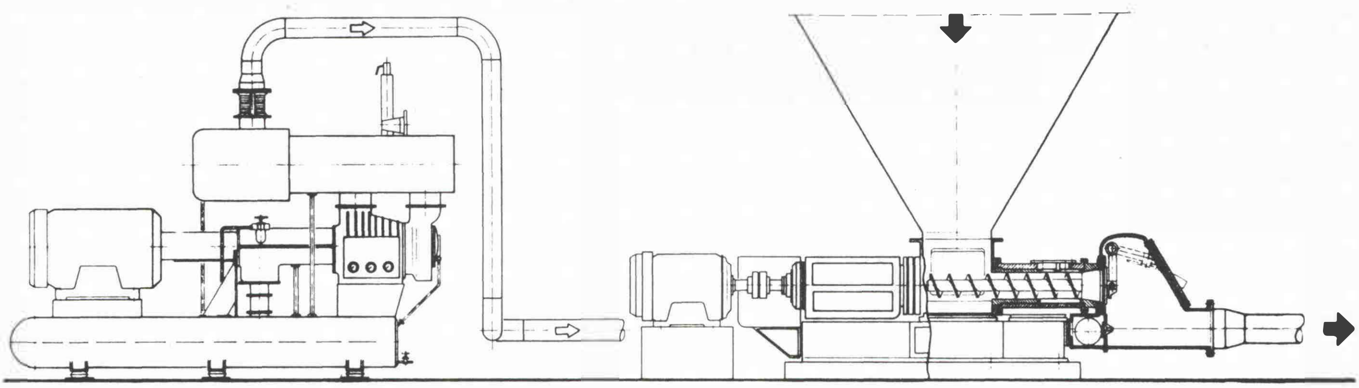

Fig. 9: Screw pump

end of the screw the material dropped into the pipeline below. The screw itself has compression, i. e., the pitch reduces on the way from inlet to exit.

Orginally these screw pumps could overcome only comparatively small pressure differences of up to about 1 bar. It was only with the introduction of an overhung screw, at the exit end of which a weighted non-return flap was arranged, that higher back pressures of up to 2.5 bar became possible. Another maker employs a screw with a high degree of compression and a special designed nozzle with the aim of overcoming higher line pressures.

In order to have a smooth running pump even under no load conditions a new design came on the market a few years ago.

This pump with non return flap and screw with bearings on both ends accepts that one gland and bearing are at the pressure end, which sometimes can have high temperatures because of hot conveying good and air.

The sealing of the pressurized space (conveying line) against the atmosphere is effected in the case of screw pumps by the conveyed material itself with the help of the fast-rotating screw. When this is borne in mind it becomes clear that these pumps no longer seal so well and without air reflux under conditions of reduced or part load. This is not always noticed and is not always a drawback, because either part-load conditions do not occur or because with reduction of load also the back pressure in the conveying line drops. But it is a drawback when such air locks receive material not continuously but intermittently, because then in periods of high conveying-line pressure insufficient material follows on to ensure an adequate sealing effect. The result is then air reflux and increased wear.

Another new design has an overhung screw with non return flap and a tapered transition piece enlarging in the direction of conveying. A plug of powdered material forms in this space and remains there at reduced or even zero load. With the aid of the non-return flap a barrier layer forms which ensures a good seal even during part-load working. Even if no further material is fed to the pump, the non-return flap will press the plug of material together. This also produces a certain wedge effect which enhances the efficacy of the seal.

Screw pumps are used throughout the world in cement works for transporting cement and raw mix. In spite of the drawback that these pumps have a high specific energy consumption and that they are subject to wear, they are nevertheless much in demand because they are small and compact, because they are simple and robust, because they are economical in price, because they have no parts that have to be acceptance-tested, and because they are easily attended by unskilled personnel.

With screw pumps one can of course transport finely-divided materials other than cement and raw mix. Now that oil is again more expensive than coal, such pumps are again being employed for the transport of pulverized coal from the mill to the storage silos, and in cement works for the transport of the coal dust from the silos to the burners of the rotary kilns and to the burners of the Pyroclones.

In such applications the pumps are often not coupled with screw compressors but with Roots type blowers. The pressure at the compressor is then usually 0.8 bar. In designing the pumps for the firing of rotary kilns and for the charging of preheaters in the cement industry, great care must be taken so that drifting and pulsation of the flow in line does not occur. If the system is correctly designed, it does not matter whether or not the pump has a nonreturn flap. In spite of what is sometimes claimed, the latter is not the cause of the pulsation. Drifting is a phenomenon which in ordinary conveying systems is put up with for the sake of saving energy.

3.4 Non-continuous high-pressure conveyor (Fig. 10)

a) Pressure range: up to 3 and 10 bar, also beyond in special cases

b) Distance: up to 2000 m

c) Compressor: single-stage and multi-stage screw or rotary compressors

d) Airlock: pressure tank

e) Material conveyed: powdered to fine-grained

f) Capacity: up to about 200 t/h

g) Remarks: Practically everyone has seen pressure tank conveyors when they are mounted on road or rail vehicles for the transport of powdered materials. The principle is as old as it is simple. The inlet is opened, the material flows into the tank until a certain highest permissible level is reached, then the inlet valve is closed, after which the tank is "pumped" to the required pressure with compressed air.

When the bottom or foot valve is opened, the conveying air and the material mingle and are transported as a dense mixture to the receiving station. There are pressure tanks with the conveying line, starting at the bottom and others where it exits from the top. As the description shows, pressure tanks are ex-

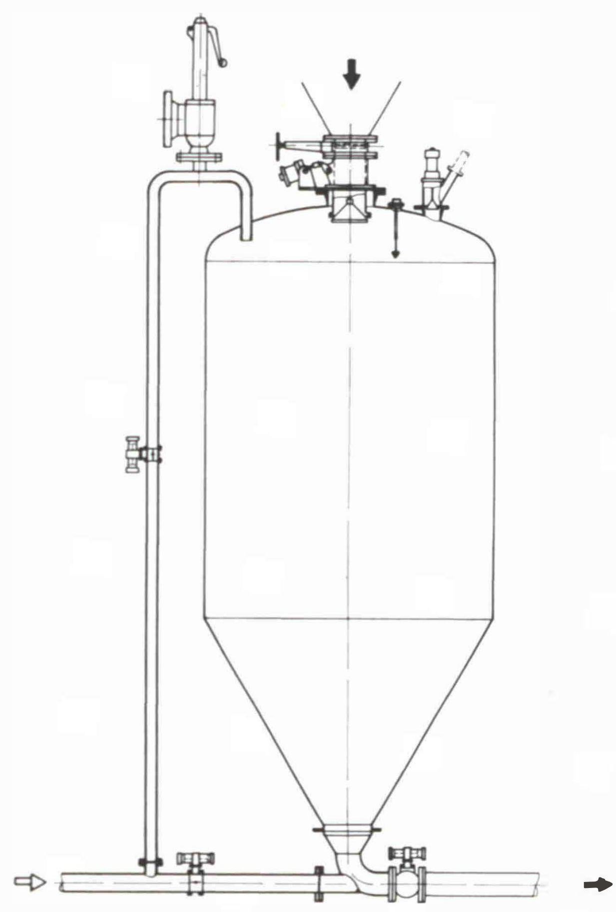

Fig. 10 a: Blow tank; bottom discharge type

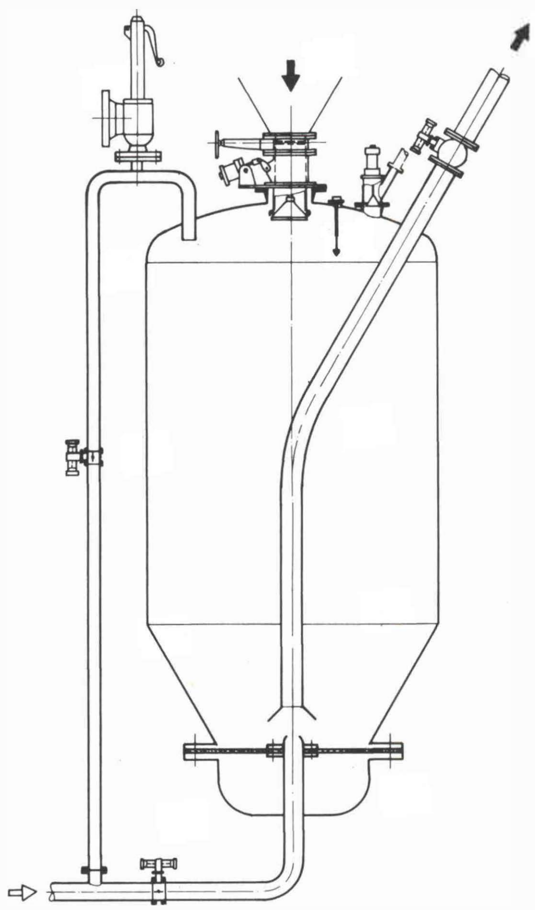

Fig. 10 b: Blow tank; top discharge type

cellent for the transportation of pulverized materials when loading takes place at one location and unloading occurs somewhere else. In such cases the pressure tank is transport container and conveying system in one.

But if the tank is only used as conveying system in a local production process, its non-continuous mode is a disadvantage, because during conveying the material which accumulates in the production process must be stored above the tank. A means of overcoming this drawback is to operate with two tanks in parallel. In very exceptional cases the tanks are connected in series, one above the other.

Such a quasi-continuous pressure-tank conveying system requires a large amount of valves, control and regulating apparatus. Such an arrangement also requires much space, and it is not inexpensive. In particular, the heights of 6, 7, 8 metres and more for large conveying plants are not always available.

3.5 Plug-type conveying

a) Pressure range: up to 10 bar

b) Distance: max. 2000 m

c) Compressor: screw compressor, rotary compressor

d) Airlock: pressure tank; also screw pump possible

e) Material conveyed: powdered and granular

f) Capacity: up to 100 t/h (200 t/h)

g) Remarks: This mode of pneumatic conveying covers the range lying below the choke point. The material is divided into many small plugs which are pushed slowly through the pipeline — rather like an unpacked parcel — with low friction loss. Bypass lines with valves can be used for introducing the compressed air.

Alternatively a perforated tube can be arranged in the upper part of the conveying pipe. This tube restricts the cross-section of the conveying line, of course, and thus reduces the possible rate of material flow, but the system is surprisingly simple. The plugs of material assume a certain length of their own accord, i. e., without outside influence; but plug formation can also be controlled at the pressure tank by means of suitably regulated valves.

An advantage of plug-type conveying is the low energy requirement. A drawback — which is a general one with pressure-tank systems — is the large amount of space required, especially the height, and the substantial first cost of the installation. Another disadvantage is that it is not possible without taking special measures to run the system down until it is empty.

4. Conclusions

Pneumatic pipeline conveying systems have many advantages, the greatest of these probably being that a simple pipe, usually of ordinary commercial quality, can be used for the transportation. The piping can be laid to suit local conditions, and it usually requires no special designing or appurtenances such as are needed for, say, conveyor belts. Transport is dust-free. Various different receiving stations can be easily served. To changeover from one station to another, only two-way valves — also called diverter valves — have to be switched over.

All these advantages of pneumatic conveying have to be bought with greater energy consumption than is the case with mechanical conveying equipment.

To conclude, something should be said about the cooling and heating of the material in a pneumatic conveying system. Customers often wish the product to be cooled or heated during transportation. This is possible to an appreciable extent only with dilute-phase conveying, i. e., with a very small solids/air mixture. The specific heat of most minerals is about 0.20 to 0.24 kcal/kg °C, while at the usual temperatures the specific heat of the conveying air is also 0.24 kcal/kg °C. It is thus apparent that with specific loadings of about 15 to 50 kg/m^3 (OTP) — which is the case with most pneumatic conveying plants — the air cannot change the material temperature to any appreciable extent. It is hoped the use of the old dimension 'kcal' instead of 'kJ' will be pardoned here, it has been done to simplify presentation.

Since the conveying gas goes on expanding in the pipeline the further it travels, its velocity increases, as was mentioned earlier. This can result in excessively high terminal velocities, especially if large resistances are encountered in the line. In such circumstances it is useful to step the line. It also allows energy to be saved, and a smaller and lower-priced compressor can often be used. Whether the pipeline should be stepped once, twice, thrice or more often, and what the lengths of the different-diameter line sections should be, that is a question which requires much expertise, which is not always available. For this reason the stepping method is not everywhere employed.

It should be noted that there are many variations, often with imaginative names, of the basic types described. There are also, for example, combined vacuum pressure conveying systems in which one compressor is employed for both the vacuum and the pressure sides and for continuous as well as non-continuous operation.

It would exceed the scope of this paper to attempt to describe all the possible variations.