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Dense Phase Pneumatic Conveying

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Pneumatische Dichtphasen-Förderung (Pfropfen- und Schubförderung)
Transfert pneumatique en phase dense
El transporte neumático en fase densa
重粉体の空気運搬
稠密相的气压输送
النقل بالناقلات ذات الطور الكثيف التي تعمل بالهواء المضغوط

Pneumatische Dichtphasen-Förderung (Pfropfen- und Schubförderung)

Die pneumatische Förderung wird zweifellos immer stärker in den verschiedenartigsten industriellen Anwendungsgebieten Eingang finden. Dieser Beitrag behandelt eingehend die jüngsten Entwicklungen, unter besonderer Berücksichtigung der Dichtphasen-Systeme (Pfropfen-, Schub- und Fließförderung) und zeigt auf, wie bisher vorhandene Schwierigkeiten überwunden werden konnten.

Transfert pneumatique en phase dense

Il est certain que le transfert pneumatique va être appliqué à une gamme de plus en plus diversifiée d'utilisations industrielles dans les années 80 à mesure que ses avantages sont plus largement acceptés. Cet exposé explique comment les développements récents de la technique, en particulier l'introduction des systèmes en phase dense, ont permis de pallier à un grand nombre de limitations associées auparavant au transfert pneumatique des solides en vrac.

El transporte neumático en fase densa

El transporte neumático se aplicará con seguridad a una diversidad siempre creciente de usos industriales en los años 80, a medida que sus ventajas vayan aceptándose más extensamente.

En este artículo se explica cómo los adelantos ténicos recientes, de modo particular la introducción de sistemas de fase densa, han logrado superar muchas de las limitaciones vinculadas anteriormente al transporte neumático de sólidos.

Summary

Pneumatic conveying is certain to be applied to an increasingly diverse range of industrial uses in the 1980 s as its advantages become more widely accepted.

This paper details how recent technical developments, in particular the introduction of dense phase systems have overcome many of the limitations previously associated with the pneumatic handling of bulk solids.

1. Introduction

The technology of pneumatic conveying is certain to be applied to an increasingly diverse range of industrial uses in the 1980s as its advantages become more widely accepted. It is possible to predict that the technique, just like materials handled in this way, will advance smoothly.

Such advance is being achieved as a result of technical developments which have overcome many of the limitations previously associated with pneumatic handling of bulk solids. It has, for example, been possible to scotch the erroneous belief that a material must be capable of being fluidised in order to be conveyed pneumatically. That is now being daily disproved by practical systems operating successfully in many parts of the world.

It has also been demonstrated that, by pneumatic conveying, solid fuel may be used automatically with virtually the same convenience as oil or gas, with which it competes. This is a matter of obvious significance at a time when coal has risen in importance in the energy policy of the developed nations.

And it has been established that the problem of heavy wear on the conveying system itself, caused by the very materials which are being handled, can be overcome satisfactorily. Such technical achievements have opened up new possible applications for pneumatic conveying, new scope for exploitation of the principle and access to a wide range of materials not previously regarded as suitable for handling in this way.

The key to the increase in potential demand for pneumatic conveying is the recent development of *dense phase systems* which do not depend on the fluidisation of the material being moved and which enable solids to be moved easily, cleanly and economically.

In the past, movement of materials such as coal for example, has all too frequently been dirty, expensive and inefficient. An examination of the conventional open conveyor systems employed at some coal-fired power stations makes the problem abundantly clear. Dust is produced all along the line.

Pneumatic conveying systems designed to handle coal, as well as sand, ash and a variety of other materials presenting associated handling problems, have recently been introduced successfully in a wide range of installations. The technology has notably been advanced by development of the Denseveyor system, manufactured by Macawber Engineering, England, which is now operating on various sites and installations throughout the world.

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2. Pneumatic Conveying Systems

The clean, enclosed handling system depends upon the successful exploitation of the dense phase pneumatic conveying technique. It is perhaps helpful at this stage to review the basic choices which are available to the engineer planning to introduce a pneumatic conveying system. Although many types of pneumatic conveying systems are available, three main concepts are of primary importance in the field (Fig. 1).

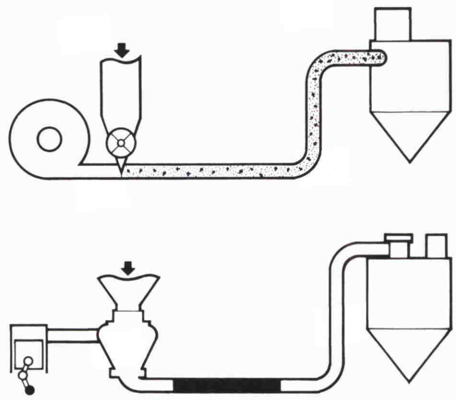

Fig. 1: Top: *Lean Phase.* Low pressure, high velocity air is required to maintain material suspension in continuous air stream. Material speed: 1370 m/min fluidised. Air to material ratio: 300 to 1
Bottom: *Dense Phase.* High pressure air is used to push a batch of material from the Denseveyor to the receiving hopper at low velocity. Material speed: 137 m/min not fluidised. Air to material ratio: 25 to 1

Lean phase systems operate at low pressure and with an air to material ratio greater than 100:1 by volume. They employ high air volumes with the material being fed continuously into the air stream.

Medium phase systems operate with an air to material ratio between 100:1 and 25:1. Either a blower or a compressor may be used, with a fluidising vessel and in many cases, further injections of air taking place at sequential points along the pipeline in order to maintain the material velocity.

Dense phase systems operate with an air to material ratio below 25:1. The system involves material being batch-fed into the pipeline and conveyed as a virtually solid slug. It can be seen that a dense phase system will require less than 25 m^3 of air (or other medium) to convey one m^3 of material over a distance of 100 m, while a lean phase system would require 100 m^3 of air to perform the same function.

In assessing performance of each of these systems the air to material ratio is obviously an important criterion, since lower ratios demand less energy consumption to handle unit volumes of material.

There are also plainly other important considerations to be taken into account. Velocity is a critical factor. Low velocities, which minimise degradation of the materials being conveyed and erosion of the pipelines through which they are being moved, are preferable. Material degradation arises from the inter-granular action of particles colliding or rolling over one another in the airstream and from contact with the pipe walls, a form of wear which may render the material unsuitable for its intended use. On top of that there may well be an increase in matter lost as fines. At lower velocity degradation is reduced and when materials are conveyed as a solid slug the risk of deterioration is removed entirely.

Material turbulence in high velocity systems leads to wear and tear of the pipework, particularly when abrasive materials are being handled. Fine particles can clog together to form lumps, continuously battering the walls. A typical *lean phase system* would move such material at more than 4.000 ft/min (20 m/sec) and wear, particularly at bends in the pipework, has always been recognised as a problem. Hardened steel pipework and massive reinforcement at bends have to be considered.

The velocity employed in any fluidised system must be high, so as to avoid "fallout", resulting in dune formation in the bottom of the pipe and eventual blockage. The necessary velocity depends on the material being handled and is a function of the mass of the largest grain being conveyed. The minimum velocity for conveying dry sand of 100 afs in a fluidised system is 3.600 ft/min (18 m/sec), for example.

With continuous lean phase systems a minimum safe conveying speed must be maintained. Fine dry powders typically travel at 2.500—3.500 ft/min (12.6—17.7 m/sec); coarse particles at 3.500—4.000 ft/min (17.7—20.2 m/sec); and larger particles at 4.500—6.000 ft/min (22.7—30.3 m/sec).

On the other hand, with *dense* or *medium phase systems* operating with a batching method, velocity may range from 100 ft/min (0.5 m/sec), a speed appropriate for granular materials such as sand, to 2.000 ft/min (10 m/sec) for larger lumps like coal and fine, light materials.

A simple formula to verify conditions in the conveying line can be used:

$$Q = V \cdot A$$

where

Q = quantity of air at the conveying pressure
V = conveying velocity
A = area of pipe

It is quite clearly necessary to determine air consumption and any measurement must show the quantity used throughout the cycle, not just the rate supplied at any one time which will fluctuate as peaking occurs.

Since the air to material ratio is critical to performance assessment, an example of its calculation may be helpful. Consider a dry sand with a density of 95 lb/ft^3 (1.520 kg/m^3), a conveying distance of 100 ft (30 m) and a 4 in. (100 mm) diameter pipe.

With a *dense phase system* a transfer rate of 15.24 t/h would be reasonable and the transfer pressure for this application would be 40 psi (2.8 kg/cm^2).

The air to material ratio would be:

$$\frac{\text{Volume of air at conveying pressure per hour}}{\text{Volume of material conveyed per hour}}$$

which is

$$\frac{32.2 \cdot 60 \cdot 95}{15 \cdot 2240} = \frac{1932\ \text{ft}^3/\text{h}}{353\ \text{ft}^3/\text{h}} = 5.47 \text{ to } 1$$

A similar application handled by a *medium phase system* would consume 600 ft^3/min of air (16.9 m^3/min) and the transfer rate would be 10 t/h with a transfer pressure of 20 psi (1.4 kg/cm^2).

The air to material ratio for this system would be:

$$\frac{254.2 \cdot 60 \cdot 95}{10 \cdot 2240} = 64.7 \text{ to } 1$$

A number of other factors are associated with the low-velocity, dense phase system. High velocity systems generate more dust at reception points and suppressing this may involve further capital costs and secondary handling systems may have to be considered.

Materials with up to 20% free moisture content have been handled successfully in dense phase systems. They have also proved capable of handling substances at high temperature (although there is, of course, an upper limit of temperature tolerance for all systems). Dense phase systems have successfully handled boiler ash and reclaimed foundry sand at up to 480°C.

In fluidised systems particle or lump size is a matter of critical importance in relation to velocity. In the *dense phase*alternative a random mixture containing lumps up to a given maximum size of 3 in. (76 mm) can be conveyed successfully.

It will be clear that there are considerable advantages in *dense phase* pneumatic conveying. High efficiency in terms of lower air to material ratios is one, less wear and material degradation because lower velocities are used is another. Improved conditions, less loss or contamination and low maintenance requirements are others.

3. The Denseveyor System

In the Denseveyor system developed by Macawber Engineering these advantages have been maximised. In particular, two major developments have made the system versatile and efficient. One of these is the specially developed *dome valve* used to seal off controlled amounts of incoming material from the hopper, the other is a series of control valves and pressure monitoring devices for precise measurement and control of material levels and air flow.

The system therefore basically consists of a pressure vessel, standard mild steel pipework and a receiving hopper controlled by appropriate level switches.

The feature of the dome valve which makes it so effective is the one-piece casting used for the dome component. Carried on stainless steel shafts, this rotates through 90° to close through the column of feed material. A pneumatic sealing ring around the valve seat operates against the upper surface of the dome to seal the vessel completely before the compressed air is allowed to enter.

The performance of this valve is more critical than may at first appear. Bulk solids do not behave like fluids and it is therefore not enough to provide a large volume of material above the start of the system. The valve must cut through the material and make an airtight seal. This is a critical aspect of application engineering and the point at which most problems occur.

Once the valve closes and the seal is effective, a precisely controlled quantity of compressed air is fed into the pressure vessel which then propels a slug of material along the pipeline.

Control of a system of this kind depends ultimately on the ability to feed precise amounts of compressed air at appropriate times to the various functional devices such as dump and switch valves. For this purpose Macawber has developed its own pressure controls and valves to ensure efficient operation of the Denseveyor systems — which use only one moving part — the dome valve.

4. Maintaining Live Storage

In many industries where bulk solids are handled, deliveries have to be made to a storage area (often in an open yard) where the material is tipped and remains until it can be transported to live storage (i.e. a hopper, bin or conveyor directly feeding a process system or feed line). With finely divided solids, such as coal and slack or similar fuels, the additional work involved in handling from dead to live storage is an unnecessary expense and inevitably the dust and spillage problem is considerable.

This aspect of handling bulk solids has largely been overcome by the introduction of the Auto-Tipper (Figs. 2a and 2b).

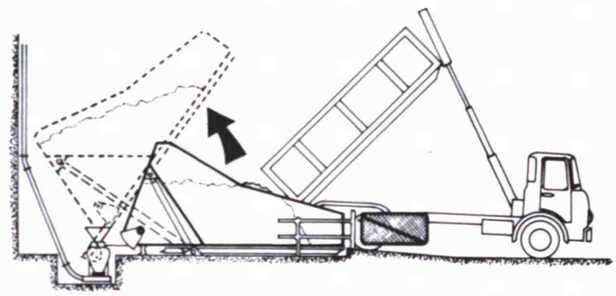

Fig. 2: Auto-Tipper and storage hopper

By serving the dual purpose of a drive-in reception platform and a storage hopper it removes the need for yard stockpiles, extensive ground excavation and costly tanker deliveries. A normal tipper lorry is enough for delivery purposes.

Lorries drive in and on to the platform immediately while the Auto-Tipper is in its horizontal position. Up to 20 t of bulk solids can be held in a plant as live storage by its use. Having deposited its load, the lorry drives away and the Auto-Tipper can be rotated vertically to become a live storage hopper delivering material directly into a Denseveyor (or any other) system.

When used in conjunction with a Denseveyor, coal from the Auto-Tipper gravity feeds into the pressure vessel for direct transport to feed hoppers over boilers or other process plants. The Auto-Tipper can therefore be remote from the feed hoppers or final storage area. The advantages of such a system both in terms of reduction in labour and handling costs as well as improvement in the working environment, are self-evident (Fig. 3).

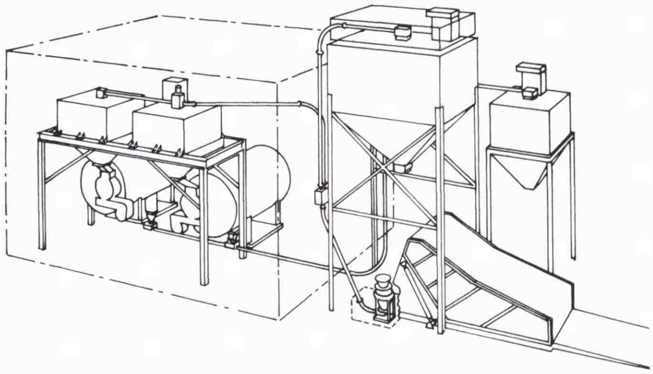

Fig. 3: Fully automatic totally enclosed coal and ash handling system with built-in live storage of fuel for weekends

In a typical fully automatic handling situation for coal and ash it is practicable to accept deliveries throughout the five-day working week and provide live storage for weekend operations. In such a situation coal is delivered into the Auto-Tipper, fed by Denseveyor into a weekend storage hopper when the relevant boiler hoppers become full. In this way gradual filling of the weekend hopper takes place throughout the week. When coal deliveries cease at the weekend, the Auto-Tipper is elevated and acts as a chute below the weekend storage hopper, feeding coal into the Denseveyor system which supplies the boiler hoppers.

5. Grit Handling System

Another new development has been a grit handling system which will make the laborious chore of manhandling the waste grit from coal fired boilers something of the past.

The Macawber Grit Handler (Fig. 4) uses the same dense phase principle as the Denseveyor to convey the waste grit from the boiler either to waste hoppers, extraction conveyors or even back into the boilers for recombustion thus maximising the calorific value of any fuel.

It uses a small pressure vessel (0.4 ft^3) incorporating the special dome valve and requires only 3.3 ft^3/min of air to handle 100 lb of grit per hour. Feeding the grit through standard mild steel pipework, the system takes all the manual handling out of grit disposal, carrying it to hoppers, bins, skips or even back to the boilers for recombustion. Again, like the Denseveyor, the system is fully automatic and totally enclosed.

A further significant factor is that, as a result of recent advances in methods and design used in pneumatic conveying, it is now quite practicable to establish in advance of installation the level of success which may be achieved with any given material.

Determining that degree of success depends upon the availability of information about the material concerned, including its grain size, moisture content, temperature, adhesive, chemical and mechanical properties.

6. Successful Applications

Despite the apparent advantages of the system for handling coal it was not for that application that it was first exploited. To some extent this was due to the conservatism of engineers, reluctant to believe that the pneumatic conveying method could provide the advantages that it appeared to promise. It was only after a number of sand-handling installations had been completed successfully at foundries in different parts of the UK that the coal-handling field began to develop and that application began to gather pace.

The degree of wide-ranging acceptance that the system has now won may be appreciated by closer examination of some of the tasks it is performing. This selection represents only a small part of the whole, indicating merely the variety rather than the number of sites where it is operating with efficiency and economy.

On the overseas front the choice of the Denseveyor for operation in boiler houses at US Army bases in Germany has been particularly significant. The US Corps of Engineers wanted a system that would automatically convey coal to the base boilers and retrieve the ash, whilst coping with the often awkward contours of boiler houses which must now be regarded as elderly. The totally enclosed and fully automatic Denseveyor was chosen because it is capable of performing that function with maximum ease of handling and minimum maintenance problems.

Another successful automatic coal-handling plant has been installed at the British Aerospace Corporation's Aircraft Division Works at Broughton, Chester, replacing a mechanical chain bucket hoist. This system transports up to 6 t/h from a ground bunker to three hoppers feeding five bunkers and uses only a single run of 4 in. mild steel pipe.

Britain's National Coal Board (NCB) is one of the major organisations which has readily come to accept the potential of dense phase pneumatic conveying. It has used the

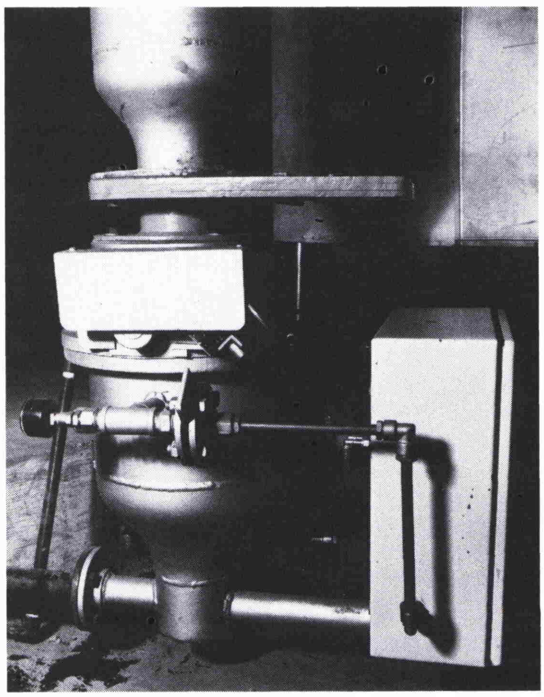

Fig. 4: Automatic and fully enclosed grit handling system

Denseveyor to demonstrate how solid fuel can be used automatically with virtually the same ease as alternative, competitive fuels — a message which is clearly of prime importance to a large scale coal producing undertaking.

There are now several Denseveyor installations feeding coal to boilers at a number of English collieries, in Yorkshire, Derbyshire and Warwickshire. Overseas, again, other installations are in service in South Africa and Australia (where national governments have provided incentives for greater use and development of their indigenous coal supplies) as well as in the USA and Germany (Fig. 5).

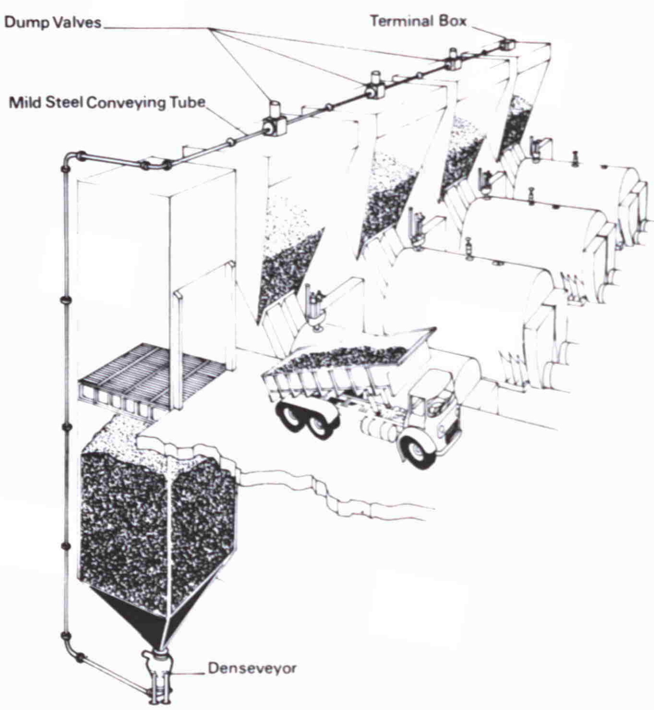

Fig. 5: A typical Macawber Denseveyor installation handling washed smalls

Among the first projects which were undertaken for the NCB in the UK was one at a new boiler house at Markham colliery in North Derbyshire. Here open conveyors had been used for carrying coal from the coal preparation plant to the boilers. When the Area Mechanical Engineer saw a Denseveyor operating at a South Yorkshire hospital he realised that a major coal handling problem — excessive dust and dirt — could be solved, apart from substantial savings in capital costs.

At Markham, one Denseveyor is sited below a hopper fed directly from the coal preparation plant by conveyor. This feeds four 10 t boiler hoppers in the boiler house 100 m distant. A second system has been installed to take coal from a ground bunker to the boiler house when direct supplies are not available. At the Worksop mine in North Derbyshire, a twin boiler installation is fed by a Denseveyor mounted below a 10 t ground hopper.

Another installation which has been operating successfully is that at the Coventry Colliery, Warwickshire, where a new boiler house was built in 1978. In this installation coal of the washed smalls type from 2—10 mm in size is handled. It is fed at up to 4 t/h through standard 4 in. steel pipework to two boilers. Hot ash is removed to a dump hopper by a second Denseveyor system.

At the Wistow mine, in the Selby coalfield of North Yorkshire, an advanced not water system was installed by Energy Equipment Company who chose a Denseveyor to accompany their microprocessor controlled fluid bed combustor. Three standard shell-type boilers with fluidized bed combustors each of $5 \cdot 10^6$ BTU/h are fired by the equipment. Coal for the combustor is fed from a storage bunker direct to the fluid-bed combustor in a fully automatic cycle. Three bunkers accept coal in bulk (which is produced within the coalfield). Each of these bunkers is served by a Denseveyor which transports the material to one of three service hoppers fitted to the fluid-bed combustors.

New materials are constantly providing a new challenge for proponents of dense phase pneumatic handling systems: Iron oxide for use by foundries is also a very dense material. Transporting it to hoppers prior to despatch proved a problem for a company, particularly as the material was at 180 °C. When loose, the bulk density is around 136 lb/ft^3 (2.178 kg/m^3) and when packed it rises to 162 lb/ft^3 (2.595 kg/m^3). Most of the manufacturers who were approached for a conveyor suggested it could not be conveyed pneumatically. Lean phase systems were inadequate.

Macawber were consulted and the end result is that the material is conveyed at 10 t/h across 125 ft from three 20 t feed hoppers to reception hoppers 30 ft above ground level. This enables it to be gravity fed into tankers for transport to customers.

One of the unusual features of this installation is that the material travels horizontally, first from the Denseveyor and then rises up to the receiving hopper, a situation not previously encountered with such a dense material.

When Westinghouse Brake and Signal Co. Ltd. changed over to cold set moulding in their foundry, sand handling underwent a radical change. Dust, noise and costly maintenance were problems that had previously been encountered and were eliminated by installing a Denseveyor. The installation includes seven pressure vessels, with two water cooled vessels handling up to 25 t/h of hot sand and a further five handling cold reclaimed sand. Handling capacity is between 5—15 t/h for each vessel. Monitoring of the levels in each silo is critical for the hot sand (450 °C) which is pushed along the pipeline in slugs of 800 lb each. So a series of probes is used to control the automatic operation and ensure immediate shut-down in the event of overloading.

Vermiculite is a constituent in fire-resistant plaster-board produced by British Gypsum of Nottingham. It can be difficult to convey and does not readily form a solid slug in the pipeline. Nevertheless, the Denseveyor system feeds it from a reception hopper a total distance of 170 ft to feed silos over the production line. The automatic system operates with very little compressed air.

Activated carbon, produced from peat, is a finely-divided black and dense material. Handling it in a modern system meant no dust, no spillage and with precise control over quantities. These were the requirements of Irish Ceca Ltd. Carbon is carried in four batches every hour from a 700 kg surge hopper via a 100 mm nominal bore pipeline to a reception hopper in the rinsing plant. Level probes in the hoppers control the feed and the filling. Another system at the same plant conveys carbon from a filter plant through a 75 mm pipeline to a central silo at 600 kg/h.