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# Pneumatic Conveying Equipment for the Mining Industry

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## Summary

The author describes heavy duty equipment for the application of dilute-phase pneumatic conveying of large-size abrasive rock or coal under rugged underground mining conditions which can have advantages over conveyor belts, bucket elevators or other forms of transport.

## 1. Introduction

Most engineers are familiar with pneumatic conveying equipment especially for handling fine grained materials such as cement, pulverized coal, and chemicals which are readily fluidized and can be conveyed by dense-phase techniques. Pneumatic conveyors are also extensively used for conveying wood chips and other such materials with low floating velocities and are of the dilute-phase type where air moving at high speed is used as the conveying medium for the particles being transported.

For dense-phase applications, air at high pressure is usually provided by a reciprocating compressor, and for dilute-phase systems a fan or positive-displacement blower is used operating at relatively low air pressures. Both dense-phase and dilute-phase pneumatic conveying systems have applications in the mining industry.

An example of dense-phase conveying especially in coal mining is the transportation of rock dust, that is pulverized limestone, to the underground workings from the mine surface for dispersal in the roadways to prevent the coal dust igniting in the event of a mine fire or gas explosion. Powdered anhydrite is also pneumatically conveyed with similar equipment and when mixed with water forms a plaster-like compound which is used for building walls or other structures to direct the air ventilation currents through the underground workings.

Dilute-phase pneumatic conveying has been applied in coal mines since the 1920s to convey rock or mine refuse into the underground workings to be used mainly for roof support in those areas where the coal has been extracted and has a secondary application that it does reduce or eliminate the disposal of rock waste on the surface of mines. In more recent years, the same technique has been applied for hoisting coal out of mines through vertical shafts in association with existing mechanical hoisting systems and also for hoisting extraneous rock from construction projects where there are no areas available for stowing the rock in the underground workings, especially if the mine is in a development phase. These systems usually operate through boreholes drilled from the surface to the underground galleries and either a single borehole is used to bring the rock to the surface with the air power source being located underground or, alternatively, the air source is located on the surface and a second borehole used to take the pressurized air underground to the infeed arrangement.

The type of equipment used for dense-phase conveying applications is similar to that used in other industries and requires no further description as this type of equipment has been well documented in previous papers. The dilute-phase equipment for handling rock or coal, although designed to the same principles as other pneumatic equipment for handling materials larger than granular size, has to be more rugged and manufactured to withstand the abuse to which machinery is exposed in an underground mining environment and for handling abrasive rocks such as sandstones. As most textbooks or technical papers published on pneumatic conveying will warn the reader of the difficulties of handling such materials and that serious consideration should be given to alternative conveying methods when handling large abrasive materials, pneumatic dilute-phase equipment is being utilized in the mining industry for such applications and the type of equipment which must be applied is the subject of this paper.

## 2. Material to be Conveyed

Prior to describing the type of pneumatic conveying equipment required for the mining industry, we should first define the term "large abrasive materials" as related to pneumatic conveying. By "large" we mean rock particles up to 3″ diameter or 3″x3″x3″ cube with several sharp edges as the rock has been blasted with explosives from the solid or removed with cutter bits on a mining machine or boring head. Mining material is abrasive in varying degrees, from coal and shales which are not too abrasive to quartzite sandstone which has nearly the abrasion characteristics of grinding wheels!

The material will not be consistent in size or shape and can consist of several types of rock in a mix, with varying densities. For example, when operating with a mine shaft boring machine which produces a mixture of cuttings as it negotiates the strata above the coal seams, the material will consist of coal, shale, sandstone, limestone, etc., produced in cubic, lenticular, or needle-like shapes depending on the material characteristics and the cutters of the boring machine. To calculate the volume of air required in a dilute-phase pneumatic conveying system, the average particle size is taken or, alternatively, the shape of the particle is considered. Hence, the reader will appreciate the difficulty of determining the average particle size or shape when designing a pneumatic conveying system to handle rock or coal particles produced from a mining operation.

The moisture content of the material will also vary considerably and will depend not only on the inherent moisture, but also on water in the mine workings, the addition of water to suppress dust by the machine cutting the coal or rock, and water added to the pneumatic system itself to reduce dust at the discharge point. The quantity of water added to the material is adjusted to bring the moisture content up to 8 % to 10 % as this not only reduces dust at the discharge, which in a backfill system is into the open mine areas with miners present, but will assist in reducing the friction factor of the material in the pipeline. However, the addition of water has to be carefully controlled, otherwise power is being absorbed by the system in conveying the water. If 5 % by weight of water is added to the material which is being conveyed at the rate of 200 t/h, then the system has to have the power capacity to convey in additional 10 t/h of material which is in effect the weight of the added water. In addition, care has to be taken that the addition of water to the material, such as clay or shales, does not increase the adhesiveness of the material and turn what is a conveyable material into one which is sticky and will build up in the elbows, pipelines, and the infeed equipment of the pneumatic system. When this occurs, additional water has to be added to take the material through the stickiness stage into a more lubricated product, although this too can be detrimental as the mine workings now become increasingly wet and, as explained above, additional power is required in the system to handle the additional weight of water. A further solution to the stickiness problem is to ensure there are a sufficient number of larger pieces of material which are not effected by the water such as sandstone or limestone which, in traveling through the pipeline, will scour the inner surface of the pipes and elbows. However, here again additional power will be required to convey the larger pieces as the average size of material being conveyed has increased. A further major effect on the capacity of a mining-type pneumatic conveying system is the friction factor between the material and the pipe walls. Although this may have been established for a particular material, it can vary in accordance to the moisture content as mentioned above and also if the system has not been in use for some days or weeks and the pipelines have a coating of rust on the inner surface. Until sufficient material has passed through the system to polish the pipelines to their normal smoothness, the friction factor can be higher than normal.

When coal is being hoisted in a dilute-phase pneumatic conveying system, as this is a combustible material, additional precautions have to be taken. Fresh air only is used as the conveying medium and not the exhaust air from the mine which could contain quantities of methane. Also, there must be no opportunity for the coal to deposit as dust in or around the equipment which, on hot spots, could cause spontaneous combustion. Water should always be added when conveying coal as this too helps to reduce the explosion hazard. If these simple precautions are observed, there is no danger in conveying coal with a pneumatic conveying system especially of the size produced in a coal mine as compared for example with coal which is pneumatically conveyed in a power plant for combustion in the boilers. Here the coal has been dried, then pulverized to the consistency of flour and, hence, is in its most highly physical explosive state. It is then ejected through a nozzle into a high temperature flame area which you would expect to create a highly dangerous situation; but as we are aware, by taking adequate precautions, the pneumatic conveying of pulverized coal is quite safe. An additional safety factor in conveying coal "as mined" is that it very often contains up to 30 % rock. This, together with its relatively large size and being wet from the sprays used on the mining machines or the water present in the mine workings, precludes the possibility of an explosion in the system.

There is often confusion within the mining industry as to the capabilities of a pneumatic conveying system to handle wet materials, and this has been due to the terminology used. Hydraulic backfill, that is where sand is flushed into the mine workings as a slurry and the water allowed to decant, is known as a "wet backfill system" whereas a pneumatic conveying system for backfill is known as a "dry backfill system." Hence, the word dry has connotations that the material being conveyed must be absolutely dry, whereas in practice it has been proven that very wet material or even water itself can be conveyed in a dilute-phase pneumatic conveying system.

## 3. Pipeline Configuration

In addition to the average particle size and character of the material changing constantly, the pipe layout also changes as the working places in the mine advance or retreat or as areas become mined out. Take for example a mine backfill system where the material is being conveyed from the surface with the infeed and air supply equipment located at the top of a borehole with a vertical drop of 900 ft, a horizontal distance underground of 1,500 ft, a 90° elbow, and a further 400 ft of horizontal pipe which also includes a couple of elbows from 45° to 90°. The discharge of the pipeline is directed into a mine opening of approximately 6 ft high by 16 ft wide. The material is crushed refuse from the coal cleaning plant which consists of shales, sandstone and water conveyed at the rate of 200 t/h. The relative density of the material when placed will be approximately 80 % and, therefore, each foot length of roadway will accommodate six tons of material. At 200 t/h, the material backfill will advance 10 ft in 20 minutes. Usually, the pipe length most readily accommodated in an underground mine is 10 ft and, therefore, the pipe has to be removed from the end of the system after 20 minutes operating time. In the course of an average shift, the pipeline length will have been reduced 210 ft. The operator has to judge from the back pressure on the system, or the blower motor load indicated by the ammeter, how much he can increase the infeed of material to the system. By the end of the next shift, it will have further decreased in length and by the end of the week will make a considerable difference to the overall performance of the system. At some time, the pipes will be re-routed into another section of the mine and may either lengthen or shorten or have to accommodate more or less elbows. In this particular example, the only fixed lengths are the borehole depth and the initial length from the borehole to the mining area. This example is given to illustrate how, unlike most pneumatic conveying systems used in industry, the length of the pipelines is constantly changing and, hence, the throughput.

As it is to the advantage of the mine to convey the maximum quantity of material at any one time, care has to be taken in those circumstances when the pipe length has been increased that the equipment operator will not continue feeding the material at the same rate as previously and, hence overload the system. In the earlier types of pneumatic systems used in the mining industry, the overloading was prevented by the operator watching closely the pressure gauge and at any sign of the pressure increasing rapidly, manually cutting off the infeed of material. This resulted in the operators tending to run the system below its maximum and, hence, at a lower efficiency, or when having their attention diverted for as little as 10 to 20 seconds, the pipeline becoming choked with material especially if an oversize piece was fed into the pipeline and became lodged in an elbow. In the more modern installations now in use in the mining industry, the infeed of material is automatically controlled by sensing the system air pressure and is always at the peak loading consistent with the pipeline length.

Several factors have to be taken into account when specifying the pipeline diameter for a mining-type pneumatic conveying system. From the theoretical point of view, the maximum pipe diameter should be chosen consistent with achieving the minimum conveying velocity and keeping the pressure of the air source to a minimum and, hence, the power required. In industrial-type pneumatic conveying systems, the economics will also be taken into consideration in regard to the higher cost of larger diameter pipes compared with the increased horsepower required for the additional air pressure to achieve the necessary flow of air through a smaller diameter, but less expensive, pipeline. A consideration taken into account in the mining industry is that men will have to physically handle the pipes constantly, especially in narrow workings in a hard rock mine or in low workings in a coal mine where vehicle transport is not always readily available or lifting equipment to load and offload the pipes. Therefore, pipes of a smaller diameter may be used, and although there is a saving in material cost with a smaller pipe and in labor cost for handling the sections of the pipe, there is a considerable increase in power to accommodate the quantity of air required to move the larger material. It is recommended that the pipe diameter should not be less than three times the largest particle size though in practice in the mining industry, 8" I.D. pipes are commonly used even though there is an occasional lump size of 3".

As the material is abrasive and rapid wear can take place in the pipeline, consideration is given to abrasion-resistant steel pipes where the inner face is hardened to 500 Bn in order to reduce the wear. There is an increase in cost compared to mild steel pipes, but is justifiable from an economic point of view providing that the wall thickness does not have to increase and make the pipes much heavier and, therefore, increase the labor cost for laying and recovering the pipelines. When handling sand, plastic and fiberglass pipes have been used although these wear more rapidly than steel pipes and are used for the last sections in the pipeline only where they are to be constantly coupled and uncoupled, and the detrimental costs in high wear rates is offset by the savings in labor where one man can carry a ten-foot length of plastic pipe compared with two men for an equivalent length of steel pipe. Rubber-lined pipes are not recommended for pneumatic conveying systems due to the high friction factor and the sharp particles of rock slicing the rubber.

The above comments will illustrate the difference in designing a pneumatic conveying system for applications in the mining industry as compared with other industrial installations. For permanent coal hoisting installations through mine shafts or rock hoisting through boreholes, the pipeline distance and vertical lift will remain constant and the characteristics of the materials being handled will also remain near constant, but can change with time as mining methods change or differing types of mining machinery are introduced into the mine. The throughput of the system will, however, frequently change depending on the time of day or portion of the working shift; for example, usually slow to start, building up to a peak, then slacking off as lunch is taken by the miners, then again reaching a peak until tapering off at the end of the shift as the miners leave their working places to make their way out of the mine. To achieve the maximum efficiency with pneumatic hoisting systems under such circumstances, storage bunkers are filled with the excess coal at the production peaks which the pneumatic system cannot accomodate, and as the production slackers off, will then discharge the surplus coal so keeping the pneumatic system at full capacity. The optimum size of bunker required is worked out with the mine operator and integrated into the pneumatic system so that the whole system becomes automatic in operation and running at peak efficiency.

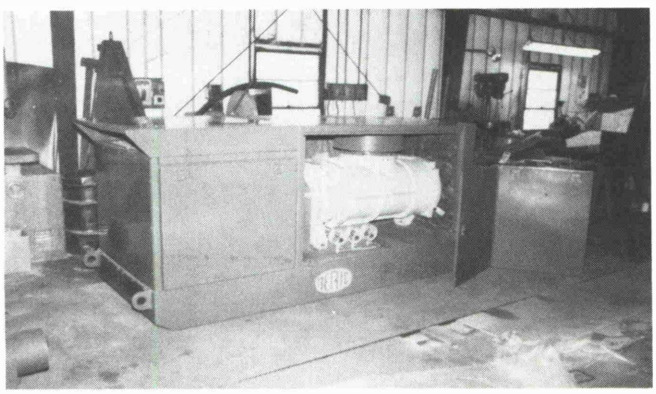
## 4. Heavy Duty Equipment

A pneumatic conveying system consists essentially of an air supply, an infeed arrangement, pipeline with necessary elbows, and a discharge. A heavy duty pneumatic conveying system also consists of these essentials but with several important differences which are necessary to accommodate the large abrasive material. Each component part is described in detail below with accompanying illustrations from which the reader will appreciate the differences in this type of equipment and that normally supplied for pneumatic conveying applications in general industry.

The air requirement for a heavy duty pneumatic system, say for example conveying 200 t/h of refuse into a coal mine, will require from 3,000 to 5,000 ft$^3$ of air per minute. With a pipeline diameter of 10", or 8" if possible, the pressure requirements for the air supply will be in the region of 15 psi and allowing for some reserve should have a maximum pressure available of 18 pounds per square inch. Such an air supply is most economically provided by a positive-displacement blower of which there are several types and makes available. This method of producing the pressurized air is probably the most economical and in most instances, blowers of this size can be direct-coupled to an electric motor operating at 1,750 rpm. Blowers of this type are simple in construction and easy to maintain, and provided they are selected to operate at a known height above sea level so that there is always sufficient volume of air flowing through the blower to dissipate the heat of compression, they will give a long life. They have one inherent disadvantage, however, that the air produced is pulsating and close to the blower itself the noise is objectionable. To overcome this problem in the confined space of a mine, the blower and electric motor are enclosed in an acoustically insulated sheet steel enclosure provided with the necessary access doors. The components are mounted on a substantial fabricated steel base with sufficient rigidity to prevent strain on either the motor, blower, or coupling when located underground in the mine on an uneven floor. As the mine air is often polluted with dust which could in time effect the blower operation by wearing the rotors and increasing the air gaps and, hence, lowering the efficiency, the air is carefully filtered before drawn into the blower by means of a panel filter which can be readily changed when necessary. The starter for the motor is mounted on the same skid-base which reduces the amount of electrical connection work the mine electricians have to undertake when these units are frequently relocated.

Being a positive-displacement machine, the pressure of the air supplied by the blower will increase according to the demands on it and if the pipeline became choked with material or should the pipeline become crushed in a roof fall, the pressure would continue to increase until the electric motor was switched off with the overcurrent relays. To ensure that physical damage does not take place, there are several protection devices built into the blower units. There is a relief valve which opens at a pre-determined level slightly below full operating pressure and at the maximum rated pressure output of the blower, say 18 psi, would be fully open relieving the excess air. This arrangement also has the advantage of keeping the pressure on the pipeline so that if a slug of material had accumulated in the pipe, it would continue to move along the pipeline until blown free. As a backup to the pressure relief valve, a rupture disc is incorporated which has to be replaced if this is blown out due to excessively high pressure. There are also a series of pressure sensing switches which operate in stages. The first to cut the infeed of material into the system and so prevent the load increasing; the second to shut down the motor should the pressure continue to increase; a third switch shuts down the motor if the air temperature becomes too high. In addition, the overload trips of the electric motor will shut off the power supply should the motor become overloaded which would again be as a result of an extraordinary high pressure (Fig. 1).

Fig. 1: Positive-displacement blower-compressor, direct driven by 400 HP electric motor



Reciprocating compressors can be used as an air supply and were used for many years in Europe for supplying air to pneumatic backfill systems in the coal mines. However, mine compressed air is usually supplied at a pressure of 90 to 110 pounds per square inch which is much higher than that required in a pneumatic conveying system of the dilute-phase type and, therefore, has to be reduced to approximately 20 psi through an orifice plate or pressure reducing valve. In the European coal mines, these compressors were already available for powering other machinery in the mine by compressed air such as coal cutting machines and drills and were, therefore, readily available for operating the backfill equipment which was most often done on a non-production shift when the other machinery would not be in use in the mine. The positive-displacement blower has, however, proven to be the most economic source of pressurized air for pneumatically conveying coal or rocks in the mining industry. (Fig. 2).

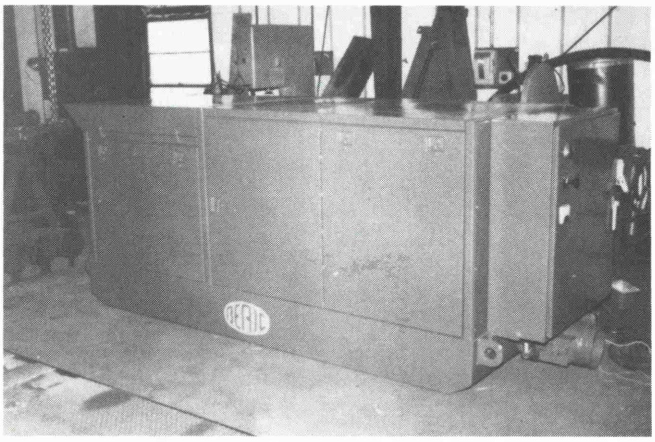


Fig. 2: Blower-compressor for mining applications, skid-base, acoustic enclosure, integral starter and air shut-off valve

There are several methods of introducing material into the pressurized air stream from atmosphere, namely: lock gates, pressure vessels, and rotary valve feeders. The only infeed arrangement suited for handling large abrasive materials is the rotary valve, or as sometimes known in the mining industry, a stowing machine. Although basically adopting the same principle as industrial-type feeders in that a rotating drum fitted with pockets carries the material from the infeed at the uppermost side around between a closely fitting inner circular face and discharging by gravity at its lowermost point into the air stream, there are major differences in the construction. A typical rotary valve used for heavy duty and handling abrasive large particles would be manufactured mainly from castings of the hardest steel available consistent with economics (Fig. 3). For example, the rotating drum or paddle wheel is a solid casting with the surfaces, which mate with the fixed components at a close tolerance, flame-hardened to 550 Bn. The pockets are set at a helix which assists with shearing the oversize pieces of rock that may become jammed at the infeed or, alternatively, will assist in moving these laterally along the rotor where they can be accommodated at the ends of the pockets and allow the rotor to turn freely. In handling such a variety of sizes of material, there will inevitably be large pieces of rock that have to be sheared and other foreign material such as wooden blocks, iron bars, mechanics' tools, etc., which, in addition to much harder rocks, cannot be sheared. If the rotary valve was powered by a high inertia source such as an electric motor, this could result in damage to the rotor.

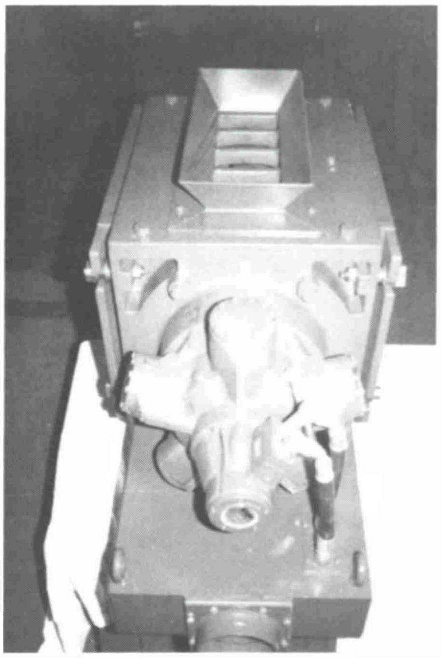


Fig. 3: Rotary airlock feeder. Drive end with high torque hydraulic motor

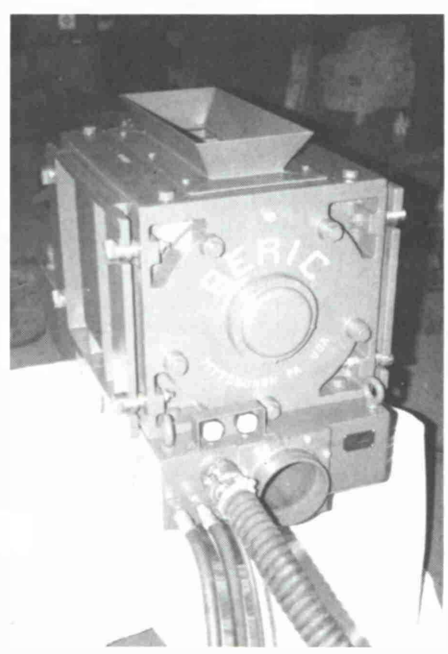
Provisions of a fluid coupling or shear pins would prevent this happening. The rotary valve shown in Fig. 3 is powered with a low speed, high-torque hydraulic motor directly coupled to the feedwheel shaft. This type of motor has the torque capabilities to shear most normal rocks or coal encountered in the mining industry, but should these prove to be unbreakable, or as mentioned above, a block of wood or steel bar, will immediately stop and the relief valve allows the hydraulic oil supply to dump to the tank and prevents damage to the feeder. It is often found, however, that a piece of rock, especially shale or the weaker sandstones, will break after subjected to two or three blows, therefore, arrangements are made that when the feedwheel is stopped suddenly as a result of such resistance, it immediately reverses for a short distance and goes forward again. It will repeat this a number of times by which either the rock will be sheared or will have been shaken down into the pocket so allowing the rotor to continue turning. In the event that the rock is unbreakable, the hydraulic motor is switched off and the alarm sounded to alert the operator, who then removes the offending article by means of safety tongs. During the forward and reversal cycle, the infeed to the rotary valve either by means of a vibrating feeder, belt or chain conveyor is switched off, and when the rotary valve continues turning, the infeed is again activated. To withstand the shock of jamming, reversing and breaking the rock, the rotary valve is designed with heavy duty parts such as a 5" diameter steel driving shaft, splined coupling to the hydraulic motor, and large heavy duty bearings.

The sides of the rotary valve, or stator halves, are also manufactured from castings and these are adjustable so that the minimum of air space exists between the rotor tips and the inner circular face. Although manufactured from Ni-Hard castings with a work-hardening property of 700 Bn, wear will eventually take place and can be accommodated by adjusting screws which move the halves inwards and so reduce the air leakage from the inducer over the rotor tips to atmosphere. The wear of the components in the rotary valve is not caused insomuch by the material tumbling through the rotor pockets as they turn from vertical upwards to downwards, but more from the effect of the escaping air around the rotor tips carrying with it fine particles of the material which then has a sand-blasting effect on the stator halves. By manufacturing these components from the hardest material available and consistent with cost, that is Ni-Hard 4, then the amount of wear or channeling is considerably reduced.

The pressurized air also has a tendency to leak around the end of the feedwheel and again by carrying the fine particles, can channel and increase the space and, hence, more air will leak. This is best overcome by pressurizing the end housings with clean air at a pressure higher than the conveying pressure and, therefore, any flow of air is outwards and does not carry with it fine particles. To supply the pressurized air, an auxiliarly blower is utilized which takes air from the system at the upstream side of the infeed and boosts this above conveying pressure for delivery into the end housings. Thus, whatever the working pressure of the pneumatic system happens to be, the air in the end housings is always that much higher and prevents ingress of dust or gritty materials into this area. The end housings which support the bearings are also manufactured from high grade steel and the exposed areas are flame-hardened. The whole unit is assembled on a fabricated skid-base which also accommodates the pipeline inducer where the material is accelerated into the air stream.

The hydraulic and auxiliary air hoses are designed for quick assembly to accommodate the regular moving of the equipment through the galleries in the mine. To illustrate the solidness and quantity of steel used in the manufacture of the rotary valve shown in Fig. 4, which has the capability of infeeding 200 t/h, of 3" rock, this unit weighs 6,000 lbs, when ready for shipping.

Fig. 4: Rotary airlock feeder. Non-driven end. Hydraulic and auxiliary air hoses



The hydraulic oil supply for the high torque motor of the rotary valve, the auxiliary air for the end housings, and the necessary backup controls for the system are contained in a separate unit called the Power Center. A typical unit is also mounted on skids and is totally enclosed to prevent dust settling on the internal parts as shown in Fig. 5. The Power Center includes a variable volume hydraulic pump by means of which the speed of the rotary valve can be adjusted to the

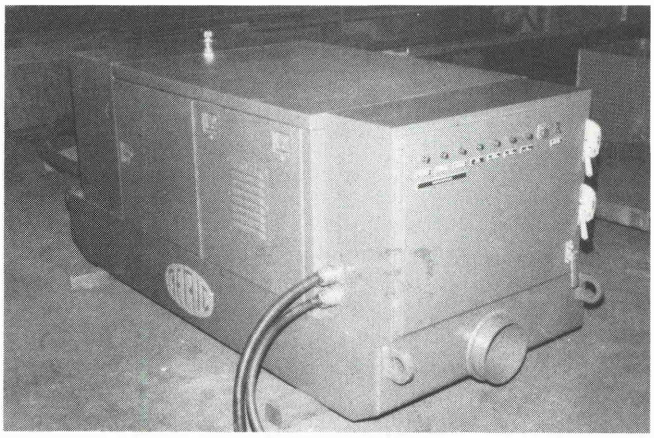


Fig. 5: Power center, containing the hydraulic pump, auxiliary blower and controls

operator's requirements, hydraulic relief valve, oil tank, filters, forward/reverse valves, together with the electrical starters for both the hydraulic pump and auxiliary blower motors and the pressure sensing devices for providing the optimum load conditions in the pneumatic conveying system. Attached to this unit by a 50 ft umbilical cord is the Control Panel shown in Fig. 6. The operator can locate this unit in a position convenient to himself from which he can

Fig. 6: Control panel. Stop/start all units, infeed control, digital pressure readout

start and stop the air supply, start all functions in the pneumatic system including the infeed arrangements and set the volume of material required to flow through the pipeline. A digital pressure readout records the air pressure in the system and is a good indication of how the system is performing. An hour meter records the total time the equipment is in operation and is useful in indicating when overhauls, filter changes, etc., are required. An emergency stop button on this unit will shut down the whole system should the operator detect a severe misperformance of the system.

The pipeline to convey the material from the infeed to the discharge point has been briefly touched upon and requires the input of the mine owner or contractor in selecting the pipe best suited to the application. The final selection can vary from mild steel thin-walled pipes to heavy-walled tubes or special steel pipes, or plastic and fiberglass pipes for conveying fine materials or in a continually moving extension of the pipeline. The pipeline should always be kept as straight as possible to reduce the wear due to impact and should also be turned regularly to even out the wear which most often occurs on the bottom of the pipeline. Where the pipeline has to change direction, elbows are used which are usually designed with replaceable cast steel bricks on the outer radius and these together with an impact section and accelerator at the discharge, will ensure the material is handled in the best possible way and is smoothly and quickly changed in direction and accelerated on its way to the next length of pipeline. Vertical elbows particularly take a high impact when located at the bottom of a deep borehole and for these applications, steel bricks manufactured from D7 tool steel are recommended. The cross-section of the castings is in the form of a "W" which helps with the aerodynamics of the material flow and ensures that the larger rocks impact on a vertical ledge and do not gouge the backing plate which often results in the start of a wear area.

As the material flows along the pipeline, the larger particles tend to bounce along the bottom, the fine particles are carried in the air stream, and the intermediate particles between; and as the various sizes fall out of the air stream, saltation takes place. The material will then form a slug which results in an inefficient system. To overcome this problem, devices known as Kickers are installed at frequent intervals in the straight length of pipeline and also after elbows which accelerate the particles of material and direct these back to the center of the air stream. The accelerated air stream is re-directed underneath the particles and, therefore, 'floats' the material over the next section of the pipeline. The location of the Kickers is not taken into account in the system calculations, being installed in accordance with experience and can be inserted or removed during the tuning of a pneumatic system when this is first installed in the mine.

To separate the material from the air stream at the discharge will require an expansion chamber or cyclone. As the cyclone must be designed for the average particle size and, hence, may not be too efficient at removing the fines, the exhausting air is taken to a second cyclone of the high efficiency type which then has the capability of backing up the main cyclone and ensuring that the air is dust free when exhausted. The air stream can also be directed into a bin, especially if the material is to be loaded into trucks and the exhaust air taken through a scrubbing cyclone. For mine backfill systems, the material is ejected from the open pipe at high velocity and the air allowed to freely flow away. It is this property of a pneumatic conveying system that makes its application attractive for backfilling mine refuse in mine galleries due to the compaction achieved when the particles impact on each other at the face of the placed material. This not only results in the maximum volume of material being confined in the minimum of space, but also helps to stabilize the support pillars and roof which will reduce collapse and subsidence at the surface.

## 5. Applications in North America

Although the technique of pneumatically conveying rocks and coal was pioneered in Europe and reached a zenith in the 1940s and 1950s in Germany and Great Britain for stowing refuse in coal mines, there have been systems installed in the mining and construction industry in North America over the past 15 years, and although not as widespread as in Europe, the number of applications are continuing to expand. In particular, the equipment has been installed in hard rock mines which is a more severe duty than found in European coal mines as the rock is far more abrasive as compared to the shale and softer materials rejected in a coal cleaning plant. Included in these applications have been the backfilling of sand in uranium mines in New Mexico; backfilling rock in mines in Canada and Mexico; hoisting cuttings from shaft raise boring machines in coal mines in Pennsylvania, West Virginia, and Kentucky; and also hoisting cuttings from a tunnel boring machine in Pennsylvania. Descriptions of many of these applications have been published elsewhere and details are readily available. Pneumatic conveying was also used to good purpose on the Alaska pipeline where the piles for supporting the overhead pipeline were pneumatically backfilled with a mixture of sand and water and to backfill the pipeline ditch in those areas where the pipe was buried. Also, to convey large quantities of material in the Thompson Pass area where the oil pipeline was installed on the mountainside over a vertical drop of 2,000 ft at a slope of between 45° and 48°. This task would have been near impossible and most expensive by any other technique. Coal hoisting from underground mines is being carried out by five mines of the National Coal Board in England and there are also two such systems in Hungary. The largest hoisting system installed to date was for the Department of Energy as an experimental and test program for operating with a Blind Shaft Boring Machine. This equipment hoisted 220 tons of 4" rock through a vertical distance of 1,240 ft and proved the capabilities of a pneumatic lift system to handle wet abrasive rock with occasional pieces up to the size of a regular brick.

The equipment described above, although basically designed for such heavy industries as mining and construction, can also be used in industry for application where the normal type of pneumatic conveying components are not suitable. For example, conveying crushed glass, iron pellets, aluminium scrap, industrial or household waste, and a multitude of other materials. The control system can be designed to work automatically and this is particularly simple for a fixed length system with a regular feed and is certainly much simpler than mining-type applications where the material, feed rate, and pipeline distances are continuously changing. For industrial applications, the rotary valve, power center, and blower-compressor unit would remain essentially the same, but would be modified to suit an industrial-type environment, for example the skid-bases may not be required. An example of this is a package being manufactured for a copper mine where all the components on the system will be located on the surface and the delivery pipeline taken down the mine shaft. For this application, all the components are mounted on a common base not more than 8 ft wide so that it can be readily transported on a trailer to the mine and on being delivered, all that is required is to connect the power source at one end and the pipeline at the other and the equipment is ready for operation. Such a package will save on installation cost at the mine, and provided a firm flat area is available to set down the package, no concrete foundations are required. Within an industrial plant, the units can be located independently of each other for example the blower-compressor in some other part of the building or, alternatively, on the roof with the rotary valve located near the storage bin and the control unit built into the overall control console for the plant.

The use of pneumatic conveying equipment will extend in the mining, construction, and other heavy industries with the availability of such equipment as described above and where previously pneumatic conveying equipment was considered to be too light, but could have been used to advantage over conveyor belts, bucket elevators, or other forms of transport. With the availability of such heavy duty equipment, the consideration of pneumatic conveying techniques for such applications can now be considered.