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Pneumatic and Hydromechanical Techniques in the Gold and Coal Mining Industries in South Africa

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Summary

Based on various task definitions from gold and coal mines in South Africa, it is explained to what extent existing techniques can be applied to the solution of these problems.

The investigation shows that experience already gained in pneumatic transport of building materials in West European coal mines provides possible solutions for the various transport requirements of South African mines; the application of pressure vessels with dosing units is a necessity.

In combination with hydraulic transport in high density pastes, further requirements in the field of backfilling can be fulfilled. Paste conveying could also provide a solution to the problem of coal dumps.

1. Introduction

The growing awareness of the limited availability of energy reserves, an increasing safety requirement, as well as a growing sensitivity to questions of pollution, present the industry with new tasks.

In order to solve these new problems, completely new methods must be developed, but, at least in some areas, solutions can be achieved by transferring well known and proven techniques.

In the following article, an attempt is made to indicate possible solutions to problems defined in the South African gold and coal mining industries by reference to proven operating processes in the field of pneumatic transport of dry bulk materials and the hydraulic transport of pastes.

The author is fully aware that all these problems cannot be solved by a simple transfer of techniques, and modifications of these will also be necessary. On the other hand, successful solutions to these problems will have a great influence on developments in the mining industry in all parts of the world.

2. The Tasks

2.1 Backfilling of Gold Mines

One of the most important problems with mining at great depths (more than 3,000 m) arises in the form of rockbursts.

Control of rockbursts appears to be possible by controlling the convergence, i.e., earth movements in the mined area. One possibility for reduction of the convergence lies in leaving pillars at pre-determined intervals as supports. However, using this method, the disadvantage is that part of the mineable material cannot be extracted.

The modern solution for convergence control, and the associated reduction or prevention of rockbursts, consists of backfilling. For this, the following materials can be employed:

— Mine tailings (slime),
— waste rock,
— mixtures of differing materials (e.g. waste rock, mine tailings, fly ash, cement).

Depending on the various backfill materials, different transport methods can be applied.

Based on previous experience, efforts have to be concentrated on the transport and handling of slimes and mixtures of various materials. Preferably, a method for the transport of slimes must be sought, since a number of advantages is achieved for the gold mining industry by the application of slime stowing:

— Reduction in the rate of energy release with a consequent reduction in the incidence of seismic events,
— improved ventilation control,
— virtual elimination of underground fires in old areas,
— decrease in the amount of stope support with a consequent reduction in stope material handling.

2.2 Utilisation of Fly Ash in Coal Mines

At present, the ash remaining after coal is burnt at a power station, is dumped in land-fill areas. The provision of these dumps requires enormous investment costs, and causes ecological problems.

As the majority of power stations are situated in the vicinity of coal mines, the opportunity exists for disposing of the ash underground. In addition to effectively avoiding the creation of large dumps for up to 4,000 t of fly ash per day above ground, further advantages are provided:

— Increased safety underground by stabilising of coal pillars,
— increased extraction rate, and an associated improvement in the economics of coal extraction.

The task which results requires the transport of large quantities of fly ash over long distances.

2.3 Dumping of Discard Coal

In South Africa at the present time, only high calorific coals are used in power stations. Lower value coals are stockpiled on the assumption that with diminishing energy reserves, there will be a future demand for them. In order to prevent spontaneous combustion, these coals are compacted, and it has been established that it is advantageous if a definite size consistency can be maintained.

The industry has thus the task of preparing suitable material mixtures, and transporting them over distances of up to 1,000 m.

3. The Techniques

3.1 Pneumatic Transport by Means of Pressure Vessels with Dosed Feeding

The necessity to minimise energy consumption has led to the introduction of high pressure systems in pneumatic transport technology, since low pressure, vacuum and circulating systems are not as economical from the point of view of energy consumption.

The development of suitable equipment for the delivery of solids into a transport pipe which is under high pressure has been concentrated on pressure vessels. All other feeding systems, in particular the widely used rotary valve system, are excluded from high pressure systems, because of their inferior pressure sealing and/or their restriction to definite product grain sizes.

Fig. 1 illustrates various designs of pressure vessels.

The mode of operation in pressure vessel systems is normally discontinuous, since the transport process is interrupted after emptying the vessel, and can only be resumed after depressurising, refilling and re-pressurising. For installations which require continuous transport, a tandem arrangement of two dispatch vessels is chosen. While one vessel is dispatching the material, the other is being filled and pressurised, so that by switching over from one vessel to the other, an uninterrupted flow of material is achieved.

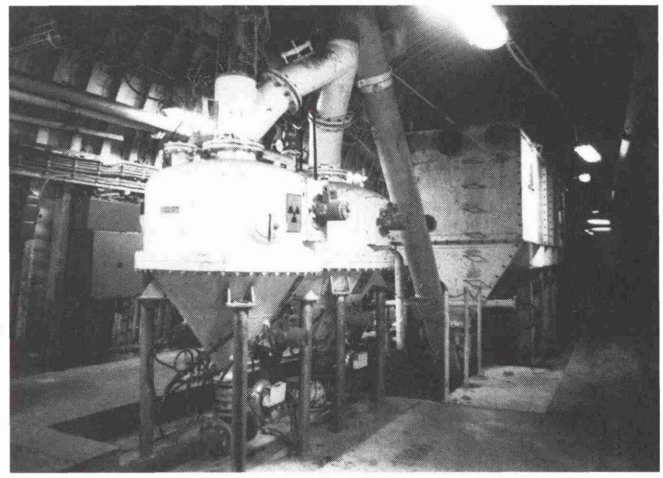


Fig. 2: Tandem dispatch station with cone dosing system for building material transport in an underground coal mine

Fig. 2 shows a tandem station, consisting of two pressure vessels with bottom discharge, each having a capacity of 1 m^3.

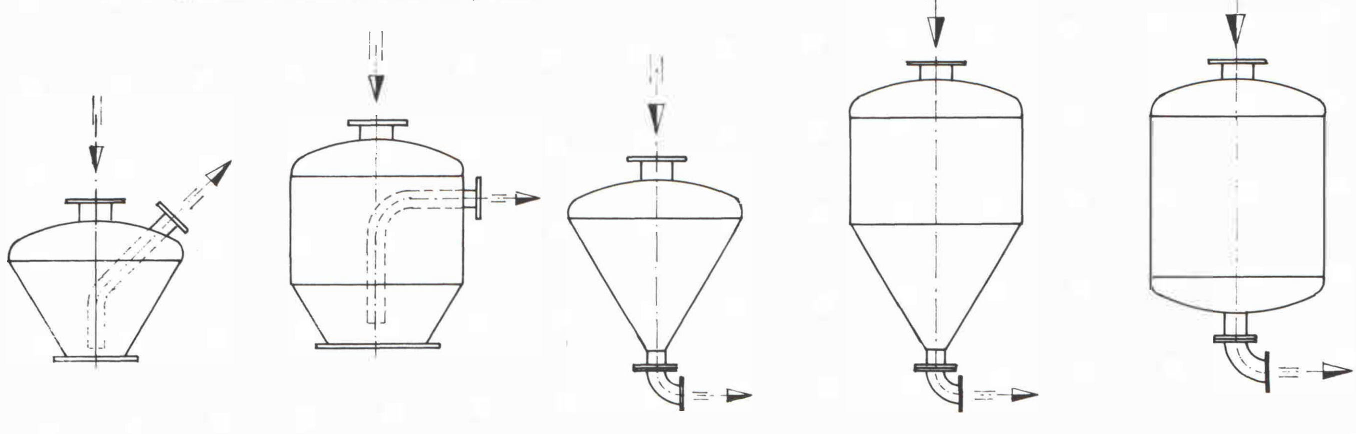
General application of pressure vessels has previously not been possible because not all products could be transported. The uncontrolled delivery of certain dry bulk materials into the pneumatic transport pipe can lead to pipe blockages. From experience, these materials include those of large grain size, as well as those which are sticky or flaky and stick together under pressure. This can also occur in some cases in the transport of small grained dry materials.

Such materials have predominantly been transported in dilute phase systems, in which the product is delivered by rotary valves, screws, etc. In addition to the associated higher energy consumption, these dosing units suffer the disadvantage that they are subject to relatively high rates of wear, particularly with abrasive materials and those of large grain size.

The following difficulties can also be observed where pressure vessels are employed:

1. Bridging within the vessel.
2. With very long transport distances, uncontrolled delivery of the material into the line leads to 'hammering'.

Fig. 1: Types of pressurised delivery vessels
a, b : Pressure vessels with submerged pipe discharge
c, d, e : Pressure vessels with bottom discharge
a, c : Small volume pressure vessels
b, d, e : Large volume pressure vessels
a, b, e : Pressure vessel for fluidisable products



Therefore, a dosing unit is required which fulfills the following requirements:

— Low-wear dosing of large and small grain size materials into the high pressure piping,
— prevention of bridge building in the dispatch vessel,
— prevention of pipe blockages,
— even flow of transported material at the end of the transport pipe.

These functions are fulfilled by the pressure vessel with cone lift dosing system shown schematically in Fig. 3.

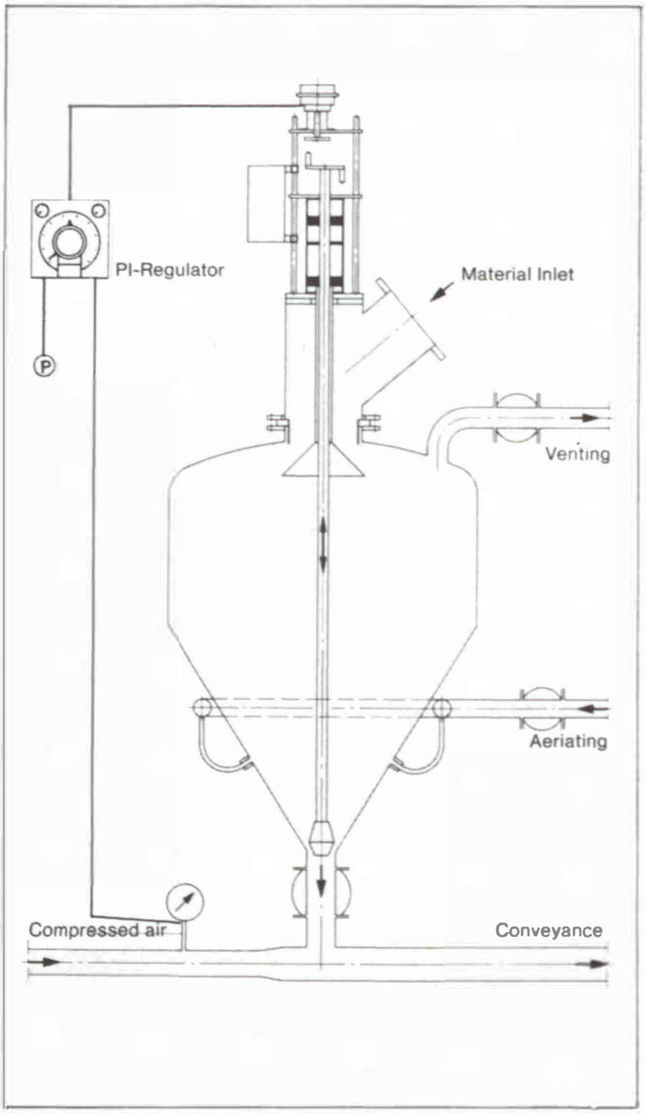


Fig. 3: Dispatch vessel with pressure controlled cone dosing system

A double cone in the exit of the dispatch vessel is moved up and down by means of a pneumatic cylinder, where either

— the stroke is constant, or
— the stroke is controlled in proportion to the pressure in the transport pipe.

In practice it is to be recommended that the pressure dependent control be adopted as on the one hand optimal loading, and on the other, because of the pressure dependent control sequence (higher transport pressure = smaller dosing travel = smaller material dosage into the transport pipe; lower transport pressure = larger dosing travel = higher material dosage) a safeguard against pipe blockages is achieved.

The prevention of production delays due to pipe blockages is alone sufficient reason for the slightly higher investment costs for the pressure dependent control system. An automatic control unit measures the transport pressure in front of the pipe in the pressure vessel and, in accordance with this pressure establishes the dosing equipment lifting height by means of a control valve.

Even with long distance transport (over 2,000 m) experience shows that because of the transport pressure dependent control systems at the input, a regular, constant material flow is obtained, so that hammering in the pipe due to the differences in the product flow is prevented, and where any requirement for the product to be wetted exists, (mining and tunnel building), the process is made considerably easier.

In addition, the motion of the dosing unit in the product improves the material flow in the dispatch vessel, since it prevents a bridge from forming.

The pressure vessels in Fig. 2 are equipped with cone dosing units.

With the application of pressure vessels, and use of high pressure transport techniques, pneumatic transport by dense phase systems (material to air ratio ≥ 30:1) is normally possible. In this case the pressure vessels require higher capital investment in comparison with the feeding units in lean phase systems, but because of the smaller gas volumes, allow savings in

— investment costs for compressor equipment,
— transport piping together with all fittings (valves, diverters etc.),
— material separators (cyclones of smaller size, filters with smaller filter area).

This statement is, however, not applicable to pneumatic transport of bulk materials over very long distances (2,000—3,000 m). Because of the high pressure losses in this form of transport, a high pressure system is indeed necessary, but the mass flow ratio (material to air relationship) is smaller. Utilisation of pressure vessels with cone dosing as dispatch units has also been successfully proved for this application.

As an example of long distance pneumatic transport under these circumstances, the system of centralised supply of building materials for underground mines, which has become a standard installation for West European mines, is presented here.

The reasons for the increasing employment of hydraulic bonding building materials lie in

— achievement of a high carrying capacity roadway,
— reduction of roadway convergence,
— protection against spontaneous combustion.

Technical data for the most commonly used hydraulic bonding building materials are given in Table 1. Fig. 4 shows in schematic form the construction of a pneumatic centralised supply installation, consisting of the surface station and two underground stations.

The pneumatic centralised supply plants are built up from modular units, so that a plant can be modified, moved, or extended according to requirements. They are composed basically of the following building groups:

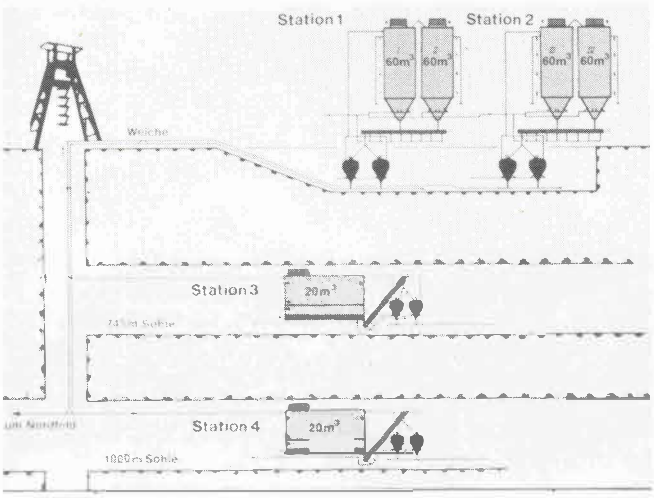


Fig. 4: Schematic representation of a centralised pneumatic supply system for building materials


Fig. 5: Surface installation for a centralised pneumatic supply system for building materials

— Building material storage above ground.

The delivery of the building materials is effected by silo-type trucks which are unloaded either with the help of their own compressors, or with compressed air available from the pit network. The stacking takes place in 1, 2 or 3 adjacent cylindrical silos with a storage capacity between 80 m³ and 160 m³.

Fig. 5 shows a surface station consisting of 4 storage silos, each 60 m³, which deliver to 2 tandem dispatch stations built directly underneath.

The standard silo is equipped with:
Silo filling conduit with overfill protection, inspection equipment, discreet or continuous filling level supervision, overpressure protection, exhaust filter, air supply equipment to silo cone, emergency closure valve and automatic closing valve on the silo outlet.

Discharging of the building material from the silo is either through gravity conduits or by screw conveyors.

— Transportation underground.

The pneumatic transport of building materials underground takes place through dispatch vessels. A single vessel is sufficient if only feeding intermediate or relay stations; capacity 2 m³, working pressure 6—10 bar. If, however, the transport is from the surface direct to the working place, a tandem pressure vessel plant with a volume of 2 x 1 m³ takes over the transport function.

The dosed feed of the building material into the transportation conduit is performed via a patented pressure-dependent controlled dosing cone. The pressure vessels in their standard form are equipped with two level indicators, cone valve for material input, venting valve for pressure reduction after the vessel is empty, contact manometer for pressure supervision, ball type discharge valve, air supply equipment for the discharge cone and the dosing cone.

The supply of building materials is initiated by demand signal from a relay station underground, or by manual operation of the surface controls.

Table 1: Technical data for hydraulic setting building materials

Characteristic	**Granular building material**		**Powdery building material**	
Description or composition	Natural anhydritic $CaSO_4$ + 1% Stimulator	Cement and limestone addition or limestone quarry sand	Cement & EFA-Filler (precipitated fly ash)	
Granulation size (mm)	0 – 10	0 – 4 (8) (16)	0 – 1	
Bulk weight (t/m³)				
loose	1.9	1.4 – 1.7	1.0 – 1.1	
sieved	2.2	1.7 – 2.0	1.2 – 1.4	
Filling factor (t/m³)	2.0 – 2.2	1.8 – 2.2	1.3 – 1.5	
Water content	0.07 – 0.1	0.08 – 0.15	0.25 – 0.3	
Crushing strength (N/mm²)			**normal**	**early strength**
after 5 h	5 – 7	1 – 6	–	5 – 15
after 24 h	20	10 – 21	6 – 16	10 – 30
after 28 d	45	30 – 40	32 – 46	30 – 50
Wear factor	1.0	0.5 – 3.5	0.01 – 0.05	

— Underground storage.

The storage bins underground, holding as a rule 10—30 m³, are constructed either similar to the storage surface silos as cylindrical bins with conical discharge or as rectangular flat bins. Filling supervision takes the form of level control, over pressure protection, inspection facilities, pressure supervision and dust filter with continuous cleaning are standard equipment for these bins.

The discharge of the building material from the storage bin is effected in the case of the cylindrical bin through gravity assisted by air pressure through the cone, and in the case of flat bins by means of a special discharge device. In the bins storing exclusively bulk materials in powder form (fluidisable), the discharge of materials takes place through a fluidisation floor, whereas in the case of bins storing granular materials, the material delivery is effected by means of a horizontal screw feeder.

In the case of extensive mine fields the underground storage bins serve as storage for the loading of mine cars. Ordinarily these bins serve to store material for attached transport equipment.

Fig. 6 shows a storage bin underground, volume 20 m³, with top mounted depressurisation filter, continuously cleaned by means of pulsating air jets, with level supervision. Material discharge via an electrically driven screw conveyor.

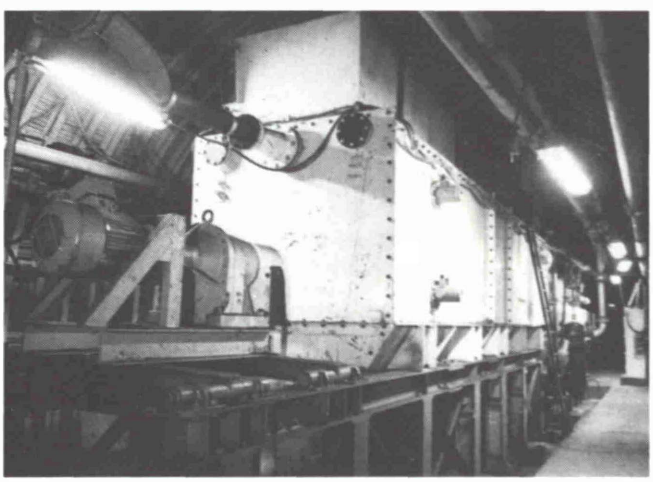


Fig. 6: Storage bunker underground, volume 20 m³

— Underground transportation.

Since most working places are supplied directly from the underground relay stations, only tandem connected dispatch vessels are employed for the transport system. Due to reduced headroom, the charging of the vessels is mostly not by gravity but through intermediate transport equipment, e.g., inclined feeder. The material transport from an intermediate relay station is initiated by direct signal from the working place or by manual start from the control cubicle.

Fig. 2 shows an underground tandem vessel station.

— Building material distribution underground.

Transportation from the surface to the underground and distribution in the mine is via transport pipes which are either seamless boiler tubes or two layer tubes with the inside surface hardened. The transport route is determined by adjustment of switch points inserted in the transport pipe. These consist of one "Y" segment and two valves. The switch points are remotely controlled and supervised by limit switches. The pneumatic transport can only start after the applicable transport route is indicated as being correct by means of return signals from individual switch points.

— Control and supervision.

The control and supervision of individual stations on the surface and underground is effected either from a pneumatic control cubicle or by means of electrically programmed controls. The control system allows the operation modes repair, interlocked manual operation and fully automatic operation. Faults will be signalled.

As a rule, a programmed microprocessor control is used for the control and supervision of centralised supply systems.

In comparison with the previously employed methods of transport, in which the building materials were brought underground, either in sacks (with considerable losses) or in open containers (with considerable dust generation), pneumatic centralised supply techniques offer the following:

1. Relief of loading in the material shaft and of the other conventional means of transport.
2. Reduction of shift costs in back-up service.
3. Provision of the required filling material in the required amounts at the required time, and greater independence of material deliveries.
4. Fully automatic operation without requirement of operating personnel.
5. Freedom from dust generation, since the system is completely sealed, and all transfer stations are sealed from the surroundings.
6. Decreased operating costs due to reduced wear in operation, and fewer operating personnel.
7. High capacity; the possibility to extend in steps, allowing optimal development according to the requirements of the mine.
8. Directed transport of large quantities of filling material for particular applications i.e., setting closure walls or fire walls. Here, in particular, the high transport capacity and low specific costs of pneumatic transport prove to be of positive advantage.
9. During mine fires, transport of building materials can continue, as nitrogen can be substituted as the transport medium, without having to change any equipment.

3.2 Hydromechanical Transport by Dense Phase Methods (Hydraulic Paste Conveying)

Analogous to the development from lean phase to dense phase operation in pneumatic techniques, it can also be established that in certain applications it will become increasingly important to transport materials hydraulically with the highest possible solids content (relationship of material to water).

This paste conveying technique is particularly applied where

— the transporting water is particularly obstructive and unwanted, e.g. in underground coal mines,
— sufficient water is not available.

In most cases, a reciprocating pump is employed for paste conveying, as this type can overcome the considerable transport resistance encountered (up to 100 bar transport pressure). Similarly to pneumatic transport with pressure vessels, it is necessary to obtain a separation between the intake area, which is under atmospheric pressure, and the pressure side. Generally, this is achieved by means of valves, e.g., ball or slide valves. In some cases, the necessary separation in 2-cylinder pumps is obtained by alternating the pressure sides.

Where valves are employed, grainy and abrasive products can cause problems, while in other applications, in particular where high transport pressures and high speed are required simultaneously to achieve the transport capacity, operating safety can be greatly diminished.

An improvement in these points is offered by a new pumping technique which can be applied to either 1-cylinder or 2-cylinder pumps. A brief introduction to this type of pump is given below.

Fig. 7 shows schematically the design and operating sequence for the pump. In Phase I, the material outlet is closed by a valve (e), which is a ball valve for powdery materials, or a butterfly valve for grainy materials. The closing cylinder (c) and the pump piston (d) are retracted. The material to be transported is sucked into the pump.

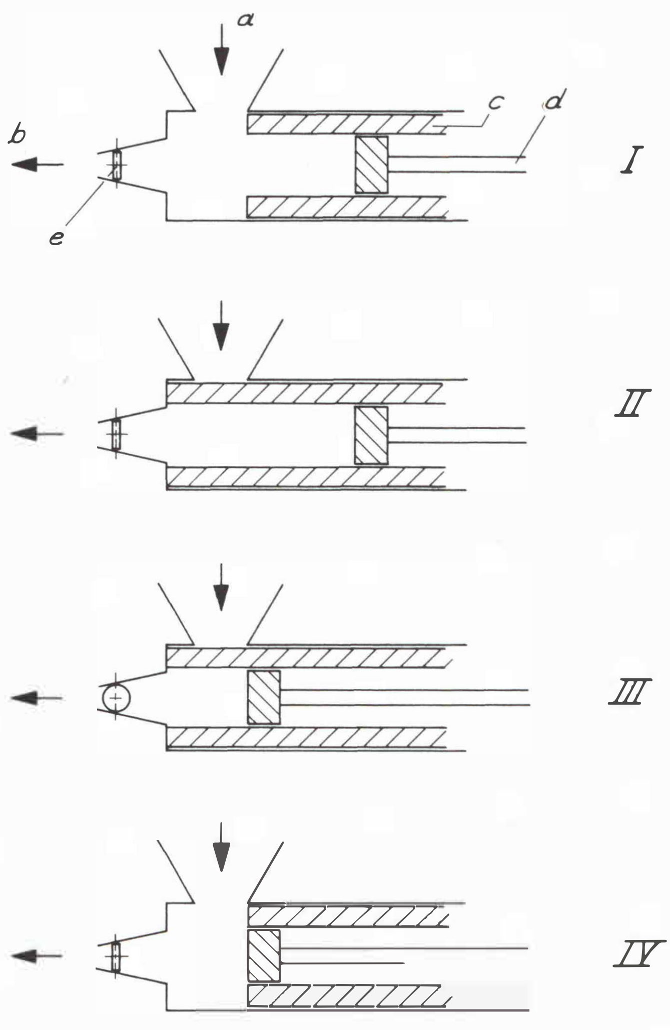


Fig. 7: New pumping principle for paste conveying
a: Material input
b: Transport pipe
c: Closing cylinder
d: Pump piston
e: Exit valve
Phase I to Phase IV: Pumping operation sequence

In Phase II, the closing cylinder is advanced, closing the material inlet (a). The closing force is related to the pressure in the hydraulic drive system, which is usually in the range of 200—300 bar. In Phase III, the exit valve is opened and the piston advanced. The material is pushed linearly out of the pump and into the transport pipe (b), whereby the pump force depends on the dimensioning of the hydraulic driving cylinder and the pressure in the hydraulic system. In phase IV, the outlet valve is closed and the closing cylinder retracted. In the subsequent phase I, a vacuum is created by retracting the piston, which sucks the product into the pump.

The following are the particular characteristics of this pumping technique:

- Transport of powdery and granular products whereby correct dimensioning of the pump piston large transport capacities can be achieved at low speeds of operation, and large transport pressures can be provided for long distance applications.
- Positive sealing between material inlet and pump cylinder by means of large closing power.
- Linear material expulsion into the pipeline, resulting in minimum wear.

The only requirement for the application of this pumping technique is that the material to be transported has to be capable of being pumped at all i.e., that it is capable of building a sliding film between the product and the pipe wall.

4. The Solutions

The keys to a solution for the tasks listed in the first section make use of the following techniques nominated in the second section:

- pneumatic transport of dry materials over long distances,
- pneumatic transport of dry materials from surface to underground,
- hydraulic transport of dry materials in dense phase mode,
- combinations of the above techniques, in that the materials are pneumatically transported over long distances from the surface to underground, and the special treatment and transport of the material to its point of application is carried out by paste conveying.

As an example, solutions for various tasks, based on these techniques, will be described.

4.1 Pneumatic Transport of Fly Ash and/or Cement over Long Distances

Fly ash and cement are delivered in bulk, particularly where requirements are large. Delivery is carried out by silo trucks or special rail wagons. Delivery by silo trucks offers the advantage that the vehicles can travel to almost any required point to unload; the disadvantage is that sometimes a much higher price per tonne of material must be paid, in comparison with delivery by rail wagons. With these statements, the advantages and disadvantages of rail transport have also been brought out — rail delivery is inflexible with regard to the point of delivery of the material, but has the advantage of lower costs.

Where a mine, which has several shafts, has a requirement for fly ash and/or cement at most of the shafts, pneumatic transport of these products from a central unloading point for rail wagons to receiving silos can be more economical than delivery by silo trucks, as long as the individual transport distances are not greater than three kilometers. In every case, high pressure transport with dispatch vessels is to be recommended, and, where the distance is greater than 1,000 m, these should be equipped with the cone dosing system.

4.2 Transport of Fly Ash into Underground Mines

Depending on the distance between the central ash storage point of a power station and the mine shaft through which the fly ash is to be blown, high pressure pneumatic transport allows either direct transport of the fly ash underground, or to an intermediate station close to the shaft. This intermediate station may consist of one or more storage silos and a secondary transport installation. From that point, the material is transported pneumatically down the shaft and into the vicinity of the point of application.

In cases where some dust generation is not a hindrance, it could be suggested that the fly ash be delivered through a wetting ring at the end of the transport pipe, where water is sprayed into the material stream, and the process is completed directly from the pneumatic transport system (open discharge). A pre-condition for this is the installation of a tandem dispatch station, since a continuous flow of material is necessary at the discharge point. The dispatch vessels must be equipped with dosing units, because of the necessity for a regular delivery of material.

Should it be necessary to ensure that no dust is generated, the fly ash must first be delivered into a storage bunker. Discharge is then effected to a mixing and pumping installation, in which the ash is continuously mixed with water and the mixture then continuously pumped in a high density paste to the point of application.

Fig. 8 shows a mixing and pumping installation, in which the dry material is conveyed to a double shafted continuous mixer by means of a screw conveyor; after mixing the material with water, the product is delivered to a hopper, from which it flows to a piston pump, which delivers it to the point

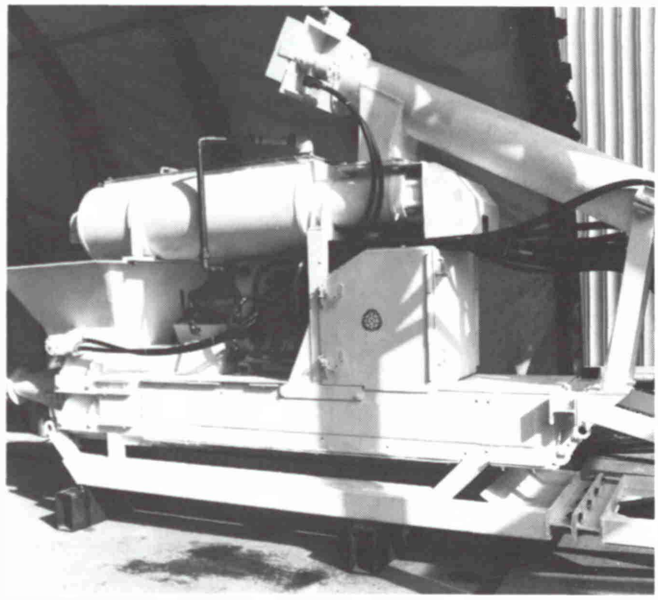


Fig. 8: Mixing and pumping installation with screw conveyor, double shaft continuous mixer and piston pump

of application. All components of this system, screw conveyor, mixer, pump are driven hydraulically.

The continuous mixer speed and the pump capacity can be continuously varied.

4.3 Cement Transport Underground

In many cases, the normal stowage of waste rock is provided with cement as binding material.

Where the demand is great enough, and the possibility of difficulties with conventional transport exists, pneumatic transport of the cement from the surface through the shaft and to the underground distribution points once again offers a solution.

Depending on the requirements, the cement can be transported directly from the surface to the final point, or to a central intermediate storage from which the material can be transported pneumatically to the individual points of application. The storage capacity for the intermediate and final bunkers is related to the individual requirements.

Fig. 9 shows schematically such a cement transport installation.

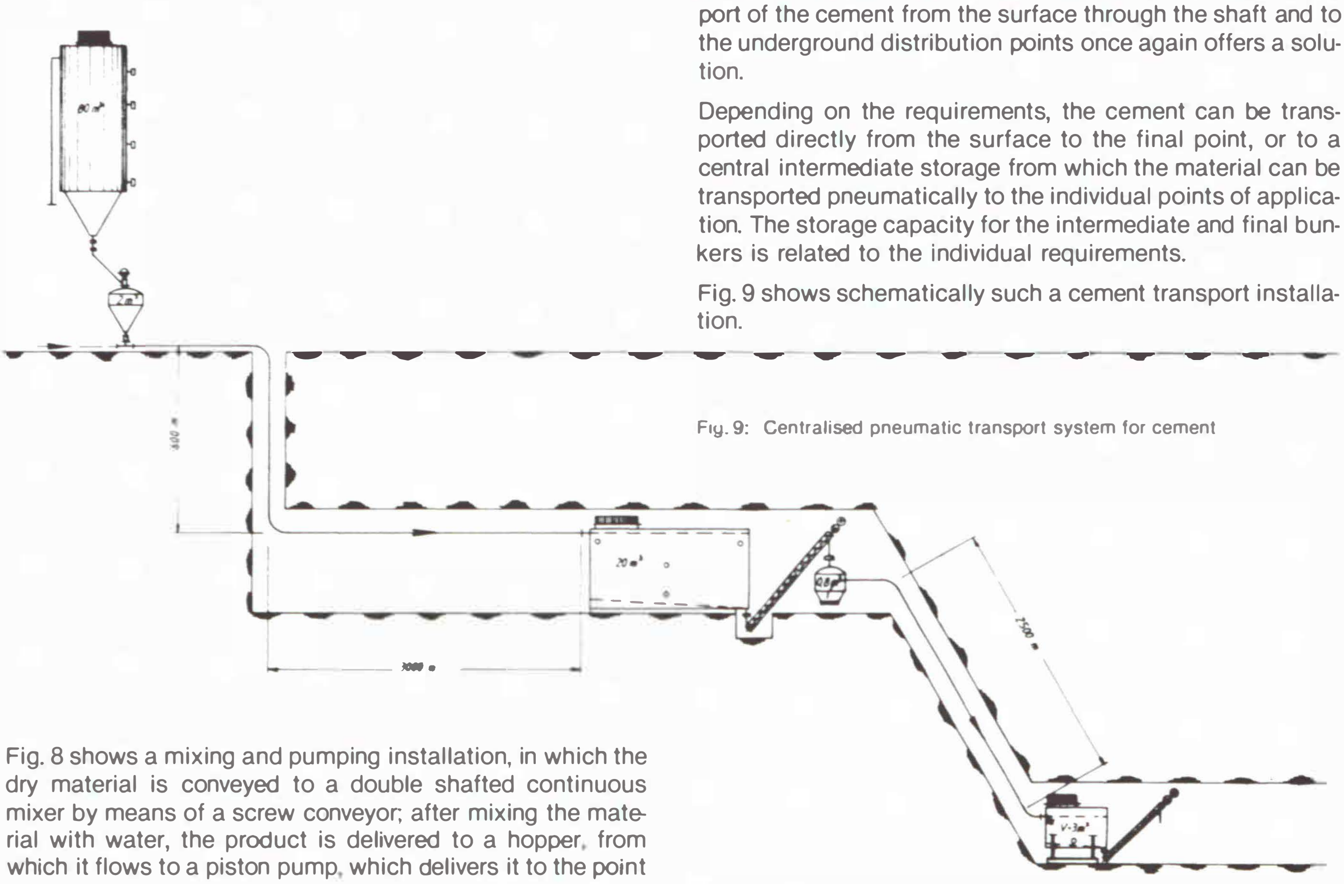


Fig. 9: Centralised pneumatic transport system for cement

4.4 Backfilling with Slimes

The system described under point 2 of this section for transport of fly ash can be applied to the transport and preparation of slimes for backfilling in gold mines. In basic preliminary tests, it has been established that this product can be dispatched from the vessels with cone dosing systems into a high pressure transport pipe, and then can be processed hydromechanically into a high density paste, with the installation shown in Fig. 8.

Further tests must be made to determine the minimum water content which is necessary in order to allow pneumatic transport; the product tends to cake together even with low moisture content, and this greatly reduces the possibility of transporting it pneumatically.

In addition, further investigations must be made into the flow and wearing characteristics of slimes, before an installation can be designed for the industry.

Fig. 10: Tandem dispatch station for continuous transport of slimes

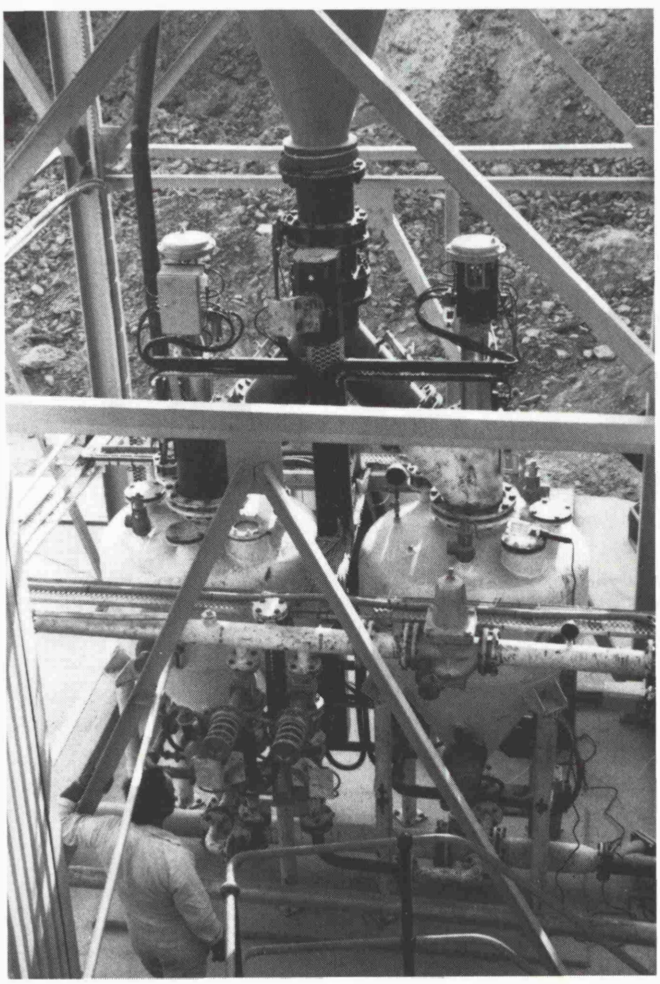


Fig. 10 shows a tandem dispatch vessel installation for the pneumatic transport of slimes. These are equipped with cone dosing units, radio-active level supervision, air quantity and differential pressure control. Control is effected by means of a programmable electronic control unit.

Photos: KBI Klöckner-Becorit Industrietechnik, West Germany

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