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Hydraulic transport systems for the backfilling of deep mines

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SYNOPSIS

The evolution of backfill-distribution systems for deep gold mines is examined. The status of current technology for the design of backfill-distribution systems is considered with reference to pipeline pressure gradients, pipeline wear rates, and slurry flow regimes.

The effect of an increase in the relative density of the slurry on the performance of backfill-distribution systems is illustrated. Future trends regarding the design of backfill-distribution systems are discussed.

SAMEVATTING

Die ewolusie van terugvuldistribusiestelsels vir diepmyne word ondersoek. Die stand van die huidige tegnologie wat betref die ontwerp van terugvuldistribusiestelsels word in oënskou geneem wat betref pyplyndrukgradiënte, pyplynslytasietempo's en floddervloeistelsels.

Die uitwerking van 'n verhoging van die relatiewe digtheid van die flodder op die werkverrigting van die terugvuldistribusiestelsels word geïllustreer. Toekomstige tendense wat betref die ontwerp van terugvuldistribusiestelsels word bespreek.

INTRODUCTION

As South African gold mines reach ever-increasing depths, it has become necessary to backfill stopes to control rockbursts and stope convergence due to excessive overburden pressure. Backfilling involves the placement of waste material (termed backfill) in the mined-out areas of a mine.

Backfill material is transported hydraulically by pipeline from the surface, where it is produced, to stopes underground, where the backfill is placed in containment barricades (paddocks). The systems conveying backfill material have been prone to operating problems associated with pipe failure, low flowrates, and pipeline blockage.

The status of the technology available for the design of backfill-distribution systems is reviewed with particular reference to pressure gradients and wear rates in pipelines. Future trends in the design of backfill-distribution systems are discussed.

EVOLUTION OF BACKFILL-DISTRIBUTION SYSTEMS

Backfill is transported by pipeline from the surface to stopes underground, where the backfill is placed in paddocks. There are two modes by which backfill is transported in a shaft column: free-fall or full-flow.

Free-fall Systems

Figure 1 shows an idealized layout for a free-fall backfill hydraulic-transport system. The backfill slurry is supplied to the shaft column in which it falls freely under gravity until it reaches the air–slurry interface. The height of this interface is established so that the static head available (due to height H_i in Figure 1) balances the frictional losses in the pressurized section of the pipeline for a particular flowrate. Thus, if the backfill flowrate is increased, the level of the air–slurry interface will rise owing to the increased frictional losses.

The disadvantages of free-fall systems are as follows.

(1) **High velocities** are attained in the free-fall zone, resulting in extreme rates of pipeline wear.
(2) **High impact pressures** generated at the air–slurry interface may lead to pipeline 'bursting' failure.

Full-flow Systems

A full-flow, or balanced backfill hydraulic-transport system is shown in Figure 2. The air–slurry interface is maintained at surface level by ensuring that the pressure head available is matched by the frictional losses in the system. The advantage of the full-flow system is that pipeline wear rates, and hence failures, are minimized. The difficulty of implementing such a system is that, for slurry velocities below 3 m/s, the static head available is far greater than the frictional losses. The following measures have been taken to dissipate the excess energy.

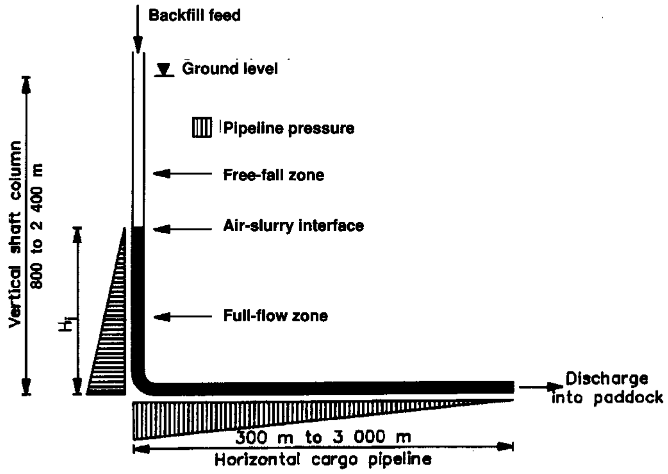

Figure 1—Free-fall backfill-transport system

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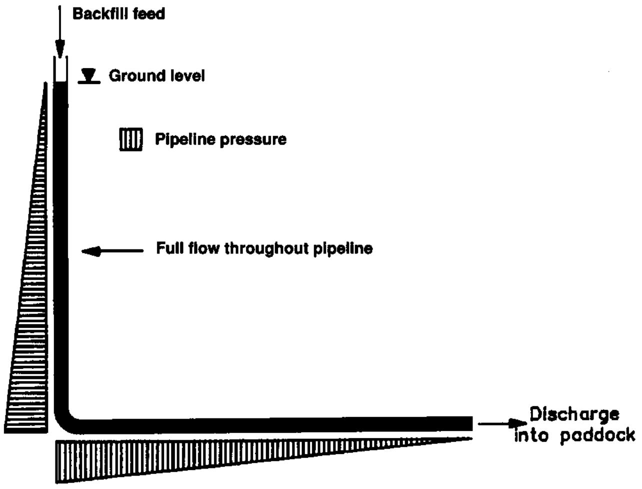

Figure 2—Full-flow backfill-transport system

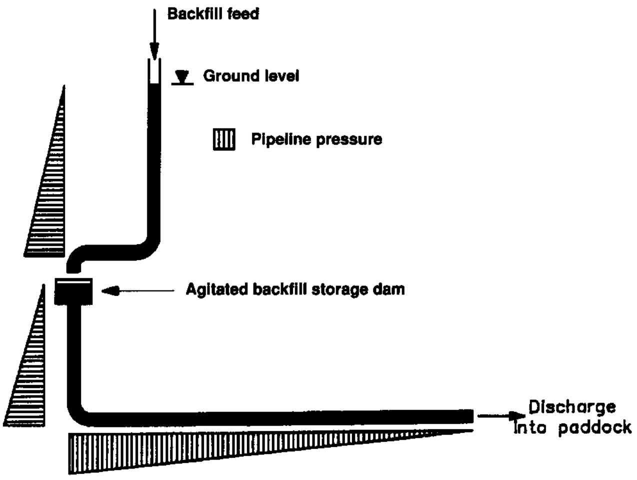

Figure 3—Pressure-break backfill-transport system

(a) *Ceramic orifices* have been installed at pipeline flanges. However, these orifices have led to localized wear downstream of the choke and, consequently, pipeline failure.

(b) *Lengths of small-bore pipe* have been installed and successfully used to dissipate excess energy. However, this is regarded as only a temporary measure since wear rates in small-bore pipelines are excessive owing to the high slurry velocities, and long lengths of pipe are required to dissipate the excess energy (typically over 500 m).

(c) Various *inline energy dissipaters* have been developed to dissipate large amounts of energy in short lengths of pipelines.

These backfill systems are referred to as dedicated-range systems since the pipeline is able to supply backfill to a maximum of only three stope panels.

Pressure-break Systems

The layout of a typical pressure-break (gravity-dam) backfill-distribution system is shown in Figure 3. The backfill slurry is supplied to an underground dam by pipes of large diameter (100 to 200 mm nominal bore). The slurry is gravity-fed from the underground dam to the stopes in pipes of smaller diameter (50 to 80 mm nominal bore).

The advantages of underground storage dams are as follows.

(i) Large-diameter pipes are used in a vertical column, considerably reducing the number of pipelines in a shaft. Consequently, the installation of the column requires minimal shaft time.

(ii) The maximum static head that can occur in the pipeline in the event of a blockage is less than that in a dedicated-range system.

The following operational problems are associated with the pressure-break system.

(1) The shaft column supplying the gravity dam generally has a relatively short horizontal distance. In order to establish a full-flow system, very high mean mixture velocities are required to balance the frictional resistance with the static head available. This leads to high rates of pipeline wear. It is preferable to operate at lower mean mixture velocities by dissipating the excess energy to ensure that full-flow conditions are maintained in the shaft column.

(2) For a particular backfill-supply pipeline from an underground dam, the static head remains constant while the horizontal distance increases as the mining and backfilling operations progress. Thus, the quantity of backfill supplied to the stopes decreases as the length of the horizontal pipeline increases.

PIPELINE PRESSURE GRADIENTS

Influence of Mean Mixture Velocity

Figure 4 shows the variation in pressure gradient with mean mixture velocity for a typical cyclone-classified tailings slurry in a pipeline of 40 mm nominal bore for various slurry relative densities. As the slurry relative density is increased, the rate of increase in pressure gradient with velocity is increased. Curves of pressure gradient versus mean mixture velocity become linear at high solids concentrations, indicating that turbulence may be negligible owing to dampening by the solid particle matrix.

Influence of Slurry Relative Density

Figure 5 depicts the variation in pressure gradient with slurry relative density for a typical cyclone-classified tailings slurry in a pipeline of 40 mm nominal bore for mean mixture velocities of 1, 2, and 3 m/s. The pressure gradient increases sharply with mixture relative density above a slurry relative density of 1,75 at all velocities.

Influence of Pipe Diameter

The variation in pressure gradient with pipe diameter is shown in Figure 6 for a typical cyclone-classified tailings slurry at a mean mixture velocity of 2 m/s for various slurry relative densities. The curves showing the pressure gradients in slurries are compared with that showing the pressure gradients in clear water. The rate of increase in pressure gradient with decrease in pipe diameter increases with increased slurry relative density.

The pipeline pressure gradient can be increased by increasing the mean mixture velocity and slurry relative density, and by decreasing the pipe diameter.

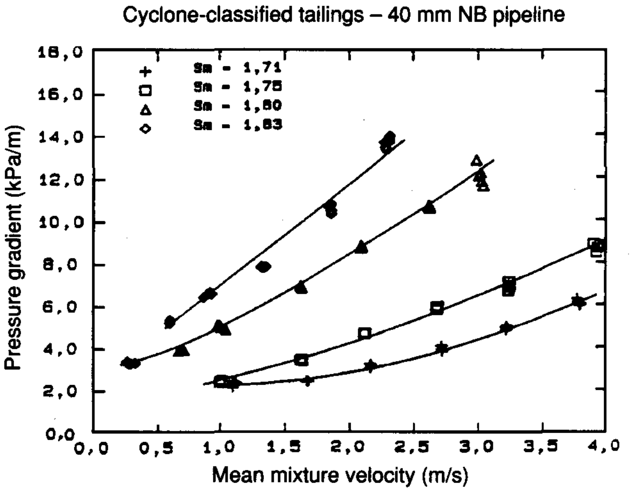

Figure 4—Influence of mean mixture velocity on pressure gradient

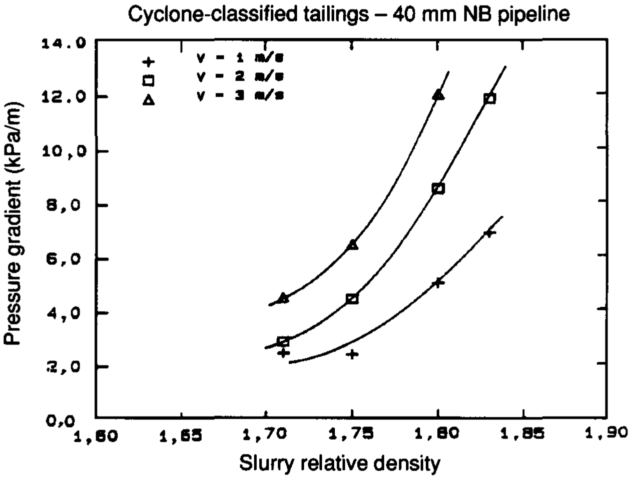

Figure 5—Influence of slurry relative density on pressure gradient

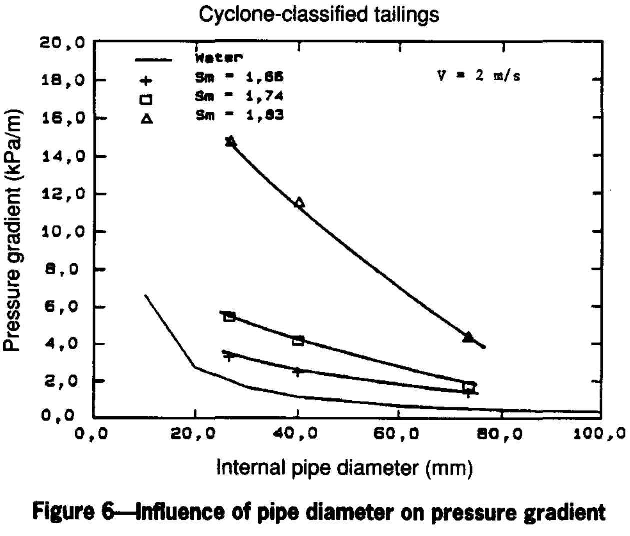

Figure 6—Influence of pipe diameter on pressure gradient

ANALYTICAL MODELLING OF PRESSURE GRADIENTS

If backfill-distribution systems are to be designed with confidence, it is vital that the pressure gradients in the pipeline should be predicted accurately. This is particularly important in the design of pressurized full-flow systems.

Mixed-regime Slurries

The Lazarus[1] mechanistic model for mixed-regime slurries (i.e. slurries with wide particle-size distributions) has been shown to accurately predict pressure gradients for slurries with relative densities of less than 1,65. Recent research at the University of Cape Town has focused on the modelling of high-concentration (high in solids) cyclone-classified tailings and full plant tailings, which behave as mixed-regime slurries at low solids concentrations. At high solids concentrations, cyclone-classified tailings form dense-phase mixtures, while full plant tailings form stabilized slurries.

Dense-phase Slurries

The dominant mechanism supporting particles in a dense-phase mixture is interparticle contact: the mixture is essentially a settling mixture in which the solid particles are prevented from settling by the high concentration of solid particles. Cooke[2] has developed a mechanistically based model to analyse the dense-phase flow of high-concentration settling mixtures, with particular reference to the high-concentration flow of backfill slurries consisting of cyclone-classified tailings. The model is based on the governing differential equation describing the velocity distribution of a solids–liquid mixture in a pipeline. The differential equation is derived by application of the Cauchy momentum equations to the solid and liquid phase of the flow. Boundary conditions particular to high-concentration slurries are applied to the differential equation, which is solved by the finite-element method.

Stabilized Slurries

In stabilized slurries, the larger particles are supported by the yield stress of the non-Newtonian carrier comprising the fine particles and fluid. Paterson[3] developed a solution procedure for the 'anomalous' non-Newtonian flow behaviour of stabilized slurries from his work on full plant tailings. The 'anomalous' flow behaviour is characterized by a diameter effect that is not explained by the constitutive equations for non-Newtonian flow. The solution procedure is based on dividing the wall shear stress for high-concentration flows into a non-Newtonian viscous portion (described by a model yield for the pseudo-plastic power law) and a portion due to particle–particle interactions.

SLURRY FLOW REGIME

Figure 7 illustrates flow observations for a typical cyclone-classified tailings slurry in a horizontal pipeline of 40 mm nominal bore. The observations are grouped into three categories:

stationary bed: a bed of stationary particles or solitary particles on the pipe invert

asymmetric flow: an asymmetric concentration profile and/or velocity profile

symmetric flow: no asymmetric concentration profile or velocity profile evident.

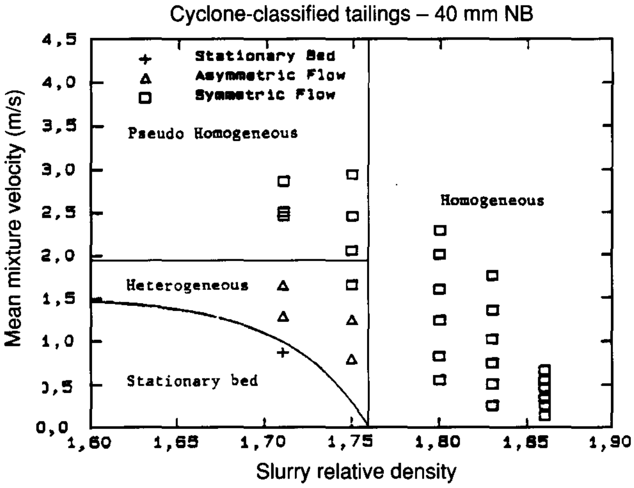

Figure 7—Flow observations for a typical cyclone-classified tailings slurry

Each flow observation in Figure 7 is plotted at the intersection of the corresponding slurry relative density and mean mixture velocity. The flow observation plot is divided into four zones:

stationary bed: zone in which the combination of solids concentration and mean mixture velocity is likely to result in a stationary bed

heterogeneous flow: flow conditions for which asymmetric velocity profiles and/or concentration profiles were observed

pseudo homogeneous: zone in which the flow appears to have symmetric velocity and concentration profiles, and in which slurries behave as heterogeneous mixtures at lower mean mixture velocities

homogeneous: zone in which the flow appears to be homogeneous for all mean mixture velocities at a particular solids concentration.

Figure 8 illustrates flow observations for cyclone-classified tailings slurry from Vaal Reefs in a horizontal pipeline of 80 mm nominal bore. The transition of these tailings from asymmetric flow to homogeneous flow occurs at a slurry relative density of 1,77 in the pipeline of 40 mm nominal bore, and at a slurry relative density of 1,80 in the pipeline of 80 mm nominal bore.

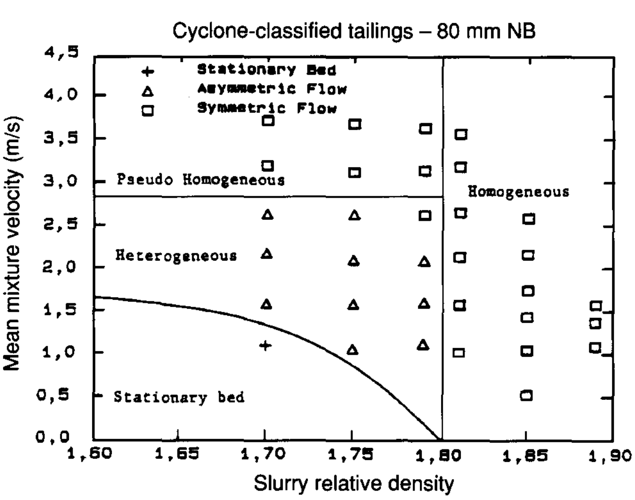

Figure 8—Flow observations for cyclone-classified tailings slurry from Vaal Reefs

The asymmetry of the flow of slurry in a pipeline decreases with the slurry's increasing relative density, and increases with increasing pipe diameter.

PIPELINE WEAR RATES

The wear rates presented in this section are based on work done by Steward and Spearing[4] and by Steward[5]. The test results are all for pipes of 0,2 per cent carbon steel.

Mean Mixture Velocity

Figure 9 shows the variation in pipeline wear rate with mean mixture velocity for a typical classified tailings slurry in a pipeline of 50 mm nominal bore at a relative density of 1,70. The wear rate is expressed as micrometres of pipe wall lost per kilotonne of solids transported through the pipeline. The rate of pipeline wear increases exponentially with mean mixture velocity, and can be expressed by the following empirical relationship:

$$\text{Wear} = KV^{n}.$$

The constant K and the exponent n are derived from experimental results, and are functions of the solids type and the relative density.

Slurry Relative Density

The influence of the relative density of the slurry on pipeline wear rates is shown in Figure 10 for a typical classified tailings in a pipeline of 50 mm nominal bore at a mean mixture velocity of 2,60 m/s. The rate of pipeline wear decreases with increasing solids concentration.

Pipe Diameter

Figure 11 shows the variation in pipeline wear rate with internal pipe diameter for a typical cyclone-classified tailings at a mixture relative density of 1,70 and a mean mixture velocity of 3,00 m/s. The rate of pipeline wear decreases with increasing pipe diameter.

Summary

The pipeline wear rate can be decreased by increasing the slurry relative density and pipe diameter, and by decreasing the mean mixture velocity.

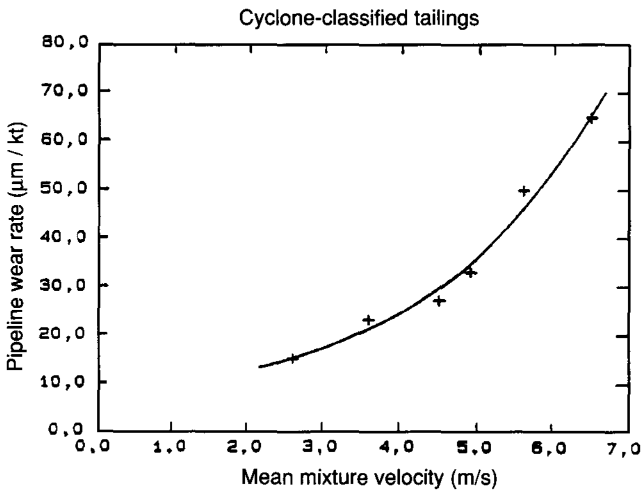

Figure 9—Variation in pipeline wear with mean mixture velocity (pipeline of 50 mm nominal bore, slurry relative density of 1,70)

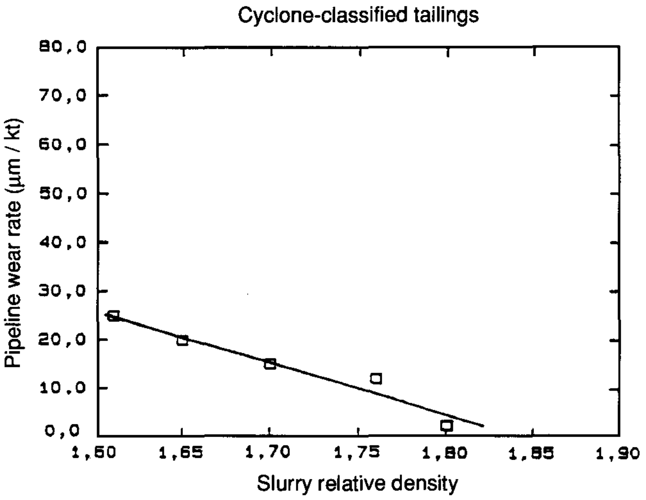

Figure 10—Variation in pipeline wear with slurry relative density (pipeline of 50 mm nominal bore, mean mixture velocity of 2,60 m/s)

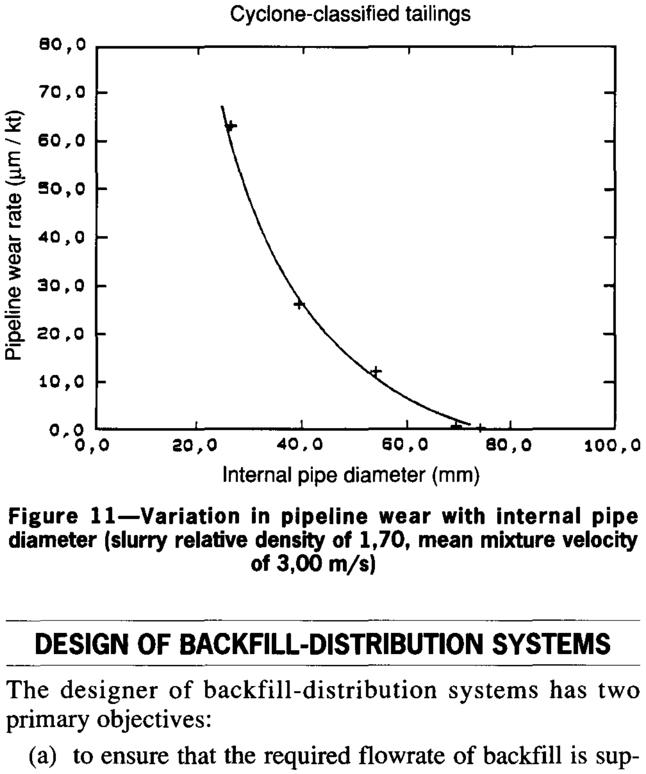

Figure 11—Variation in pipeline wear with internal pipe diameter (slurry relative density of 1,70, mean mixture velocity of 3,00 m/s)

DESIGN OF BACKFILL-DISTRIBUTION SYSTEMS

The designer of backfill-distribution systems has two primary objectives:

(a) to ensure that the required flowrate of backfill is supplied to the paddock to maintain the mining cycle

(b) to maximize the life of the pipeline and so reduce shaft downtime and replacement costs; this can be achieved only by a full-flow system, which requires that the pipeline frictional losses should equal the energy due to the static head.

The pipeline frictional losses can be increased by increasing the mean mixture velocity and the slurry relative density, and by decreasing the pipe diameter. The pipeline wear rates can be decreased by increasing the mixture relative density and the pipe diameter, and by decreasing the mean mixture velocity. Thus, an increase in the slurry relative density advantageously affects both the pipeline frictional losses and the wear rate.

In illustration of the effect of increased slurry relative density on the performance of a backfill-distribution system, consider a typical dedicated-range backfill system with a shaft column height of 2000 m and a horizontal distance of 3000 m.

With a schedule 80 pipeline of 50 mm nominal bore and a slurry relative density of 1,70:

To achieve full flow in this case, a mean mixture velocity of 4,52 m/s is required. This yields a flowrate of 30,9 m^3/h, which is adequate. However, the pipeline wear rates will be high owing to the high mean mixture velocity.

With a schedule 80 pipeline of 50 mm nominal bore and a slurry relative density of 1,80:

In this case, because of the increased pipeline frictional losses, a mean mixture velocity of 2,09 m/s is required to achieve a balanced system. Although the pipeline wear rates will be reduced owing to the decreased mean mixture velocity and the increased slurry relative density, the design is not suitable since the flowrate is inadequate (14,3 m^3/h).

With a schedule 80 pipeline of 65 mm nominal bore and a slurry relative density of 1,80:

To achieve full flow in this case, a mean mixture velocity of 2,98 m/s is required, which yields a flowrate of 29,3 m^3/h. This design is suitable since it meets the required flowrate and decreases the pipeline wear rate by increasing the slurry relative density and pipe diameter, and by reducing the mean mixture velocity.

FUTURE TRENDS

Highly Concentrated Backfill Slurries

There are many advantages associated with highly concentrated backfill slurries, and it is likely that the future trend will be towards backfill systems of higher relative density. The following are some of the advantages of operating at increased slurry relative densities:

(a) higher pressure gradients, which reduce the amount of excess energy available and permit the utilization of larger-bore pipes

(b) reduced slurry flowrates due to the lower water content of the slurry

(c) reduced pipeline wear rates

(d) reduced water run-off after placement

(e) shorter consolidation time for backfill

(f) lower additive costs for cemented-backfill slurries.

Prior to the implementation of backfill-distribution systems operating at higher slurry relative densities, the following aspects need to be investigated.

(i) The backfill material produced should have a high relative density.

(ii) As the pipeline pressure gradients are extremely sensitive to changes in slurry relative density at high slurry relative densities, control of the relative density of the backfill entering the distribution system is critical.

Cemented-backfill Slurries

Cemented backfills are finding increasing application, particularly in mines with large stoping widths. Preliminary research[6] has shown that cemented backfill slurries may have lower pipeline wear rates than uncemented-backfill slurries. The effect of additives on pipeline pressure gradients should be investigated.

Rational Design

The replacement of pipelines in mines is costly as a result of the shaft downtime during the installation, and it is thus critical that the pipeline wear rates should be minimized to maximize the life of the pipeline. There are two ways in which this can be done.

(1) **Design of backfill systems.** The backfill-distribution system should be designed to minimize pipeline wear rates by taking cognizance of the influence of mean mixture velocity, slurry relative density, and pipe diameter on pipeline wear rates as discussed earlier.

(2) **Selection of pipelining material.** Pipelining materials such as polyurethane and high-density polyethylene have substantially improved wear characteristics compared with those of steel. However, care must be taken to ensure that quality-control standards are adhered to during the pipelining process.

A successful backfill-reticulation system should incorporate both of these factors to ensure maximum possible pipeline life. A major benefit of the use of lined pipes is that the pipeline pressure factor of safety does not change with time, as is the case with unlined steel pipelines.

CONCLUSIONS

(a) Sufficient knowledge is available on the behaviour of backfill slurries with regard to pipeline wear and pressure gradients to permit the rational design of backfill-distribution systems.

(b) The operation of backfill systems at higher slurry relative densities will improve the performance of backfill-distribution systems, provided that operational problems associated with the production of the backfill and the control of relative density are solved.

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BRANCH News

Gala Dinner, Eastern Transvaal Branch

A gala dinner hosted by the Eastern Transvaal Branch of the SAIMM was held at the Midway Inn, Middelburg, on Wednesday, 18th November, 1992.

The dinner was held in honour of Mr J.P. (Hannes) Hoffman, President of the Institute for 1992/3, and the first person from the Branch to attain this position. Hannes has lived in the region since 1974, and has served for many years on the Branch committee. He also serves on the SAIMM Council.

Richard Jennings was Master of Ceremonies, and the Branch Chairman, Mr Mike Rogers, chaired the evening's proceedings.

Mr Fred Boshoff, the Chief Executive Officer of the Columbus Stainless Project, gave a short and interesting talk on the Columbus Project. Mr Hannes Hoffman replied to this talk.

Mike Rogers then presented commemorative crystal glasses to both speakers and bouquets of flowers to their wives.

Approximately 170 members and guests attended the function, which was organized by Messrs Brian Bell, Alistair Henderson, and Paul Henry. The function was also well supported by a cross-section of companies connected to both mining and metallurgical industries:

Voest-Alpine Mining & Tunnelling (Pty) Ltd
Scharrighuisen Open Cast Mining (1989) (Pty) Ltd
Mannesman Demag
Melco Mining Supplies
Barlows Equipment Co.
Fraser Alexander Bulk Materials Handling (Pty) Ltd
AECI Explosives & Chemicals Ltd
O & K Orenstein & Koppel (SA) (Pty) Ltd
Highveld Steel & Vanadium Corporation Ltd
Dorbyl
Moolman Bros. Construction Company
Bucyrus Africa (Pty) Ltd
Mastertreads
Columbus Stainless
Joy Manufacturing Co. (Africa) (Pty) Ltd
Multotec Group of Companies
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