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The effect of particle sharpness on the wear of backfill pipelines

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SYNOPSIS

The relationships between backfill-transportation parameters (solids concentration, velocity, and pipe diameter) and the wear rate of backfill-transportation pipelines is well understood. However, the degree of wear experienced by a pipeline depends not only on the transportation parameters, but also on the characteristics of the solids making up the backfill, i.e. the particle-size distribution, hardness, shape, and sharpness of the particles. Therefore, unless data corresponding to the specific wear rate of the solids are available, the determination of the wear rate for pipes transporting an uncharacterized backfill is largely guesswork.

This paper describes an evaluation of particle characteristics with special reference to particle sharpness so that pipe wear rates can be correlated with solids of different size distributions and sharpnesses.

SAMEVATTING

Die verhouding tussen die terugvulvervoerparameters (konsentrasie van vaste stowwe, snelheid en pypdiameter) en die slytasietempo van terugvulvervoerpypleidings word deeglik begryp. Die mate van slytasie wat 'n pypleiding ondervind, hang egter nie net van die vervoerparameters af nie, maar ook van die eienskappe van die vaste stowwe wat die terugvulsel uitmaak, d.w.s. die partikelgrootteverdeling hardheid, vorm en skerpheid van die partikels. Tensy daar data oor die spesifieke slytasietempo van die vaste stowwe beskikbaar is, is die bepaling van die slytasietempo van pype wat 'n ongekaraktiriseerde terugvulsel vervoer, dus in 'n groot mate blote raaiwerk.

Hierdie referaat beskryf die resultate van 'n evaluering van partikeleienskappe met spesiale verwysing na die skerpheid van partikels sodat die pypslytasietempo's met vaste stowwe met verskillende grootteverdelings en 'n verskillende mate van skerpheid gekorreleer kan word.

INTRODUCTION

Attempts to develop an equation to correlate pipe wear with the parameters of transportation for a range of solids, such as backfill solids, has largely resulted in failure owing to an inability to describe the sharpness of particles. Particle sharpness is often confused with particle shape, and a definition of each is therefore in order. *Particle shape* is typically evaluated through a comparison of a particle's geometry with that of a known shape, i.e. a sphere; the particle is then described according to its deviation from that shape, or through measured diameters of the particle, which are then compared with known geometries, i.e. rectangular, oblong, etc. *Particle sharpness* according to Steward and Ruther[1] concerns, not the total area of a particle, but what happens on the particle's perimeter. To this end, particle sharpness can be described as the change in direction of a particle's perimeter, and the rate of that change over the length of perimeter in which the change takes place. The measurement of this particle angularity or sharpness is also described by Steward and Ruther[1].

The effect of particle characteristics on the wear rate of pipe materials, specifically size and sharpness, has been reported as follows.

- As the particle size increases, so does the pipe wear rate of a pipeline[2–11].
- Sharper particles cause greater wear than rounded particles[4,7,9,11–16].

In the evaluation of the angularity index (AI) given in this paper, the wear results from three test procedures involving different backfill slurries either eroding or abrading a metal surface are compared. The evaluation was based on two sets of results generated by Steward[17–22], and on a set of data generated independently by Shannon and Sityebi[23].

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EXPERIMENTAL METHODS

Apparatus and Sampling

Figure 1 shows the closed-loop pipeline rig that was used in this research to generate the required rates of pipe wear. The rig is described in detail by Steward[24]. The slurry reservoir has a capacity of 1,8 m^3 within which the solids are kept in suspension by agitation. The pump is a Warman 4/3 D centrifugal slurry-handling pump driven by a hydraulic variable-speed motor. The velocity and concentration of the slurry are monitored by means of a magnetic flowmeter and weigh tank respectively. Mild-steel heat exchangers are used to maintain the temperature of the slurry in the pipeline at approximately 25°C. The diameter of the exit orifice of the pipeline is smaller at the point where the slurry is returned to the slurry reservoir so that a jet of slurry is generated.

Two test procedures[24–28] were utilized in this work, and are discussed separately. It is necessary to distinguish between the test procedure and the particle analysis used. The test procedure is a process producing worn particles and pipe materials. The analysis procedure is the evaluation of the change in particle characteristics in relation to the wear rate achieved.

Procedure in the Jet-impact Tests

This procedure uses the jet of slurry generated when the slurry returns to the slurry reservoir. Flat specimens of the pipe under test are kept in position below this slurry jet by means of a holder to which they are bolted. The conditions of testing are summarized in Table I.

The pipe material evaluated in this research was mild steel (ASTM A106 Grade B). Two specimens of mild steel were evaluated sequentially in a single test run of 360 minutes. The initial exposure time to the slurry was 5 minutes per specimen. This results in an interval of 5 minutes between a specific specimen's exposure to the jet of slurry, i.e. two specimens were exposed to the jet of slurry alternately. After approximately 3 hours, the impact exposures were increased to 20 minutes per specimen until the wear rate levelled off for each of the three specimens, after which the test was terminated. The total test time was 6 hours. After each test run, the slurry was disposed of and a new slurry was mixed in the slurry reservoir.

The wear rate in grams per hour of each specimen was calculated from the weight of each specimen before the test, obtained to an accuracy of 10 mg on an electronic balance. After each subsequent exposure to the slurry jet, the specimen was dried and reweighed. Drying involved the removal of any excess water from the steel specimen with a towel, and then removal of the residual dampness with a hair dryer. The specimen was then allowed to stand until it was required for testing, at which stage it was weighed and the mass noted. The resultant losses in mass were converted to a wear rate of grams per hour and plotted against the lifetime of the slurry.

Procedure in the Pipeline

The sections of piping for evaluation were joined as shown in Figure 2. All three sections were of the same material, in this case ASTM A106 Grade B mild-steel pipe. This method allows for the central section of pipe to be accurately aligned with the lead-in and lead-out sections of the pipe, resulting in a smooth flow of slurry through the central section, which is then measured for the rate of material removal. The pipe specimens were weighed to an accuracy of 10 mg prior to testing.

Table I

Jet-impact test parameters

Velocity of slurry at nozzle	m/s	16,5
Relative density of slurry		1,30
Temperature of slurry	°	25
Impact angle of specimen	°	20
Duration of specimen's exposure	min	120
Total duration of test	min	360

The slurry was run at the required relative density and velocity through the closed-loop pipeline for 9 hours. The test sections were then dismantled, and the central section of each spool piece was weighed and measured for material loss. These results were then converted to a reduction in wall thickness per tonne of material transported.

Sampling of Solids

Representative samples of the slurry being circulated in the closed-loop pipeline were obtained by the use of a 50 mm Slurry King diverting valve sited in a section of vertical pipe (Figure 1). The reason for siting in the vertical is that the distribution of solids across the pipe is more uniform there. The operation of the valve results in the entire flow of slurry in the pipeline being diverted to a sampling bucket. This prevents any problems that may arise from the testing of unrepresentative samples from the pipeline. The particles in the samples were then characterized.

Analysis of the Solids

Sieving

The solids, after being taken from the pipeline, were dried in a drying oven for 24 hours at 90°C, after which they were separated into different size ranges by sieving. Such separation is necessary when samples are to be analysed under a stereo microscope, especially when there are likely to be depth-of-field problems due to large variations in particle size. The depth of field pertains to the ability of a microscope to focus on both the farthest and the closest extremities of a particle at the same time. If a large particle lies alongside a small particle, only one may be focused on while the other is distorted over its area owing to the inability of the instrument to focus over the total vertical distance required. The sieving was carried out with Frietsh wire-mesh screens, and the size ranges analysed are indicated where required. Also, the particle-size distribution was determined for each bulk sample by use of a Malvern laser particle sizer.

Preparation of Samples

For images suitable for semi-automatic image analysis, i.e. images having the greatest contrast to the chosen background, the most representative and easily managed sample should be prepared. The first operation involves the taking of a sample that is representative of the total solids population. This is done with a riffle on the sieved, dried sample taken from the closed-loop pipeline. The riffle is an apparatus that randomly partitions a large sample into two smaller samples, and so on, until a random sample size suitable for analysis is obtained. The size of sample that can be managed by the image-processing system must be

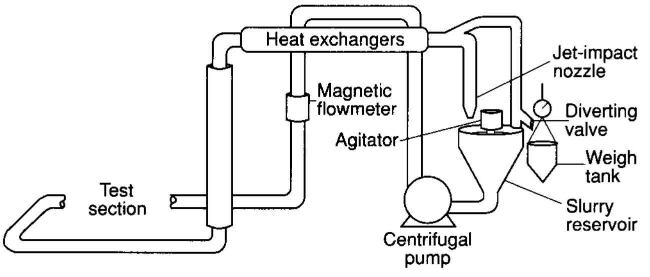

Figure 1—Closed-loop pipeline rig

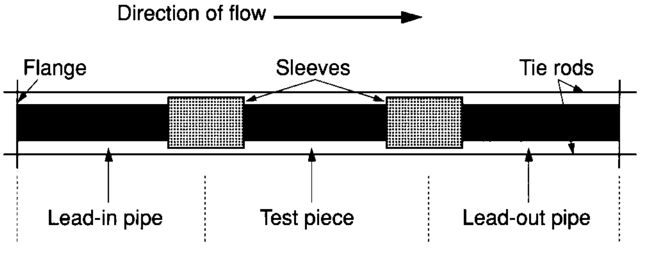

Figure 2—Configuration for the pipeline tests

considered when samples of solids are taken. Subsequent to the riffling of a suitable sample, the following techniques are used to prepare the sample for maximum contrast under imaging conditions.

Background and Illumination

In the analysis of particles, a black background is produced on which white particles can rest (a binary image). This was achieved by the use of backlighting techniques and strips of polaroid film. A ring light attached to a cold light source was placed beneath an opaque sheet of plastic to diffuse the light. Two strips of polaroid film were placed one on top of the other and orientated at 90 degrees. This polaroid system was then placed on top of the plastic sheet over the light source so that the light was effectively prevented from being transmitted through the polaroid system. A white alumina tube large enough to enclose the light source was then placed on the polaroid strips. However, the polaroid strips were not large enough to prevent the entrance of light into the tube, i.e. light could enter the alumina tube from around the sides of the polaroid strips. The tube extended up to the lens of the microscope, cutting out any surrounding light (daylight, room lights, etc). The particles to be analysed were sprinkled on the surface of the two polaroid strips, and the alumina tube evenly reflected the light infiltrating round the polaroid film from all directions onto the particles. The particles were then viewed as milky white on a black background. This technique was extremely effective.

Selection of the Camera Lens

Two types of lenses can be considered as attachments to the CCD camera: the macro-lens, and the microscope. The macro-lens is used without the microscope when the size of individual particles is too large to be accommodated in the microscope's field of view. The microscope is used in analyses where the surface characteristics of the particles would be lost when the macro-lens is used owing to its inability to magnify particles as effectively as a microscope does.

Test Materials

The pipeline material used in this research was ASTM A106 Grade B. Sands from various sources were used in the slurries so that, when transported through the closed-loop pipeline, they would show different wear rates and different particle characteristics. The following sands were used:

- Cycloned tailings (CT) from
  - Elandsrand (ER)
  - Vaal Reefs East (VRE)
  - Vaal Reefs South (VRS)
  - Western Deep Levels South (WDLS)
  - Western Deep Levels West (WDLW)
- Full-plant tailings (FPT) from
  - President Steyn (PS)
  - Vaal Reefs East (VRE)
  - Western Deep Levels South (WDLS).

Figures 3 and 4 illustrate the particle-size distributions for these sands.

RESULTS

Table II lists the wear results for the solids tested in the jet-impact test, and Table III gives the wear results for the solids tested under pipeline conditions. The AI was calculated from the results shown in Figures 5 to 10.

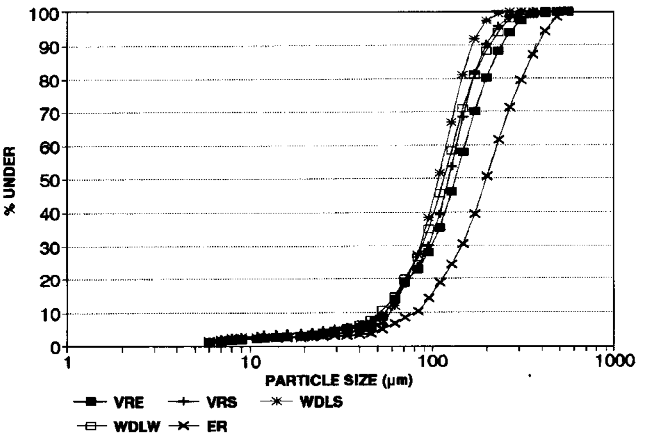

Figure 3—Particle-size distribution of the cycloned tailings tested

DISCUSSION

The AI as derived in this way[1] depends on the extent to which the particles have been magnified. To achieve a representative AI for a specific sample of solids, the relationship, as calculated by use of a least-squares fit, between the AI and the particle size, shown in Figures 5 to 10, is obtained. The average particle size is then chosen and the AI is calculated from the linear relationship determined from the graphs. In the present work, a particle size of 200 pixels was chosen as the standard particle size. Table IV lists the AIs that were calculated for the materials tested.

The effect of particle size and sharpness on the wear rates obtained in the jet-impact and pipeline tests is that, as the

Table II
Results of the jet-impact test

Type of solids	Wear rate g/h
Full-plant tailings:	
Vaal Reefs East	0,5
President Steyn	0,4
W. Deep Levels South	0,3
Cycloned tailings:	
Elandsrand	1,3
W. Deep Levels South	0,9
Vaal Reefs South	1,1
Vaal Reefs East	1,2

Table III
Results of the pipeline tests

Conditions:
- Relative density of the solids: 1,70
- Velocity of the slurry: 3,00 m/s
- Diameter of the pipeline: 54,20 mm

Type of solids	d_{90}	Angularity AI	Wear rate m/t
Full-plant tailings:			
President Steyn	193	0,0164	0,00717
W. Deep Levels West	200	0,0155	0,00801
Cycloned tailings:			
Elandsrand	260	0,0160	0,02230
W. Deep Levels South	195	0,0150	0,00750
Vaal Reefs South	215	0,0190	0,00989
Vaal Reefs East	240	0,0200	0,01500

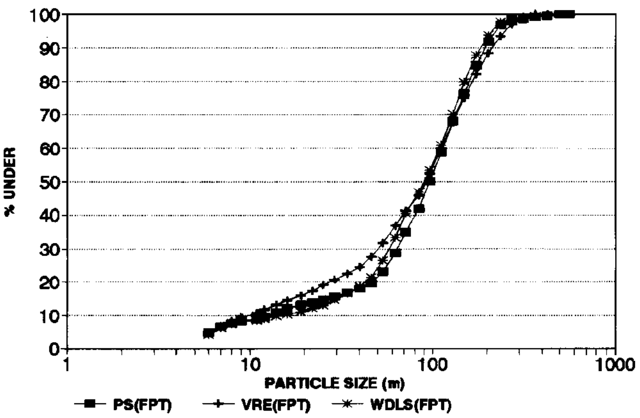

Figure 4—Particle-size distribution of the full-plant tailings tested

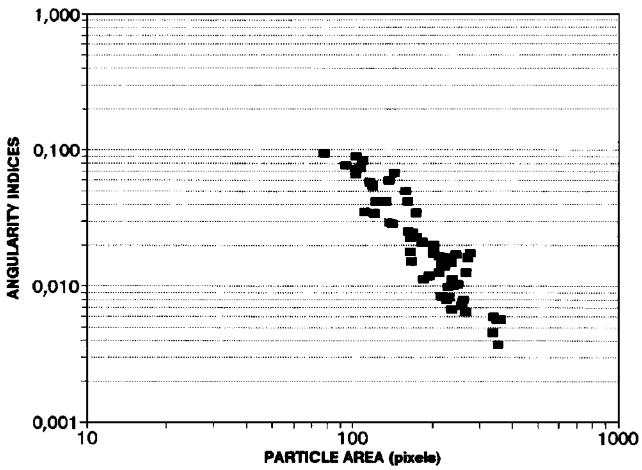

Figure 5—Relationship between angularity index and particle area for cycloned tailings from Elandsrand

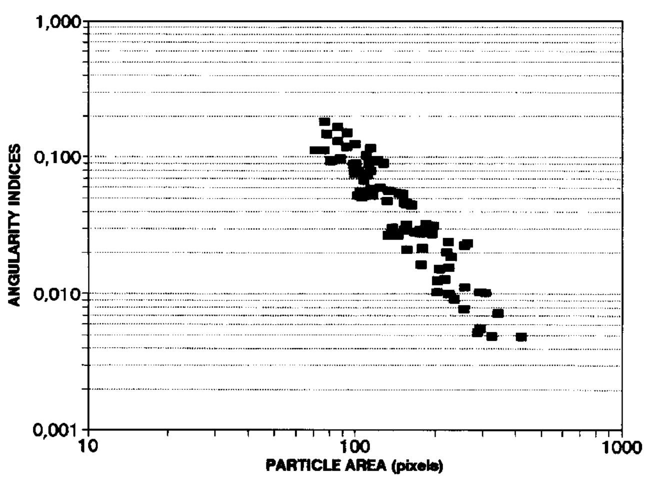

Figure 6—Relationship between angularity index and particle area for cycloned tailings from Vaal Reefs East

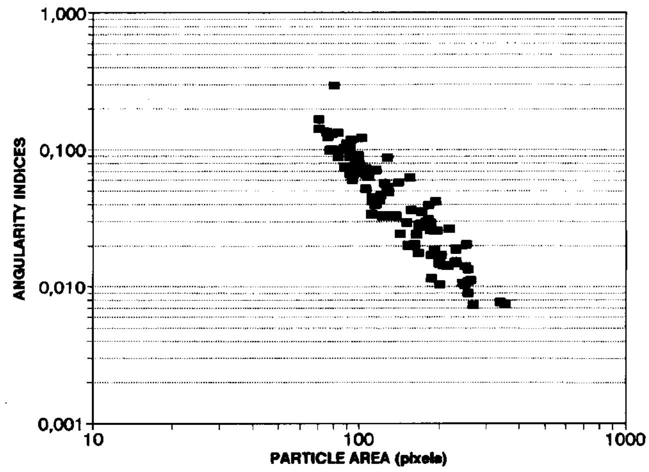

Figure 7—Relationship between angularity index and particle area for cycloned tailings from Vaal Reefs South

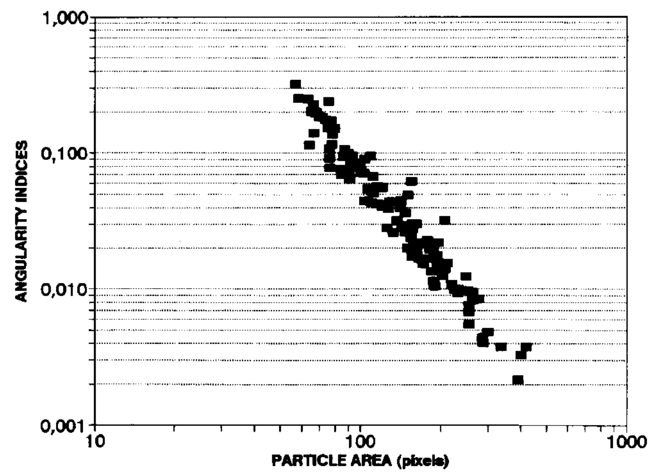

Figure 8—Relationship between angularity index and particle area for cycloned tailings from Western Deep Levels South

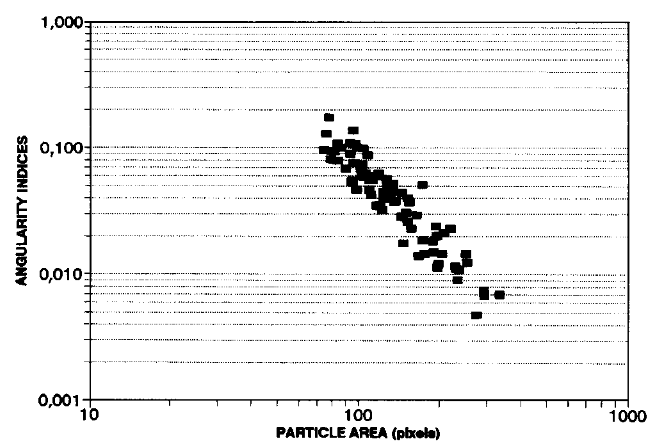

Figure 9—Relationship between angularity index and particle area for cycloned tailings from Western Deep Levels West

particle size and sharpness increase, so does the wear rate. In this respect, Figures 11 and 12 show particle size versus wear rate normalized for the effect of particle sharpness, i.e. the wear rate was divided by the particle sharpness. The particle size is characterized by the particle-size distribution d_{90}. (The d_{90} is the particle size at which 90 per cent of the particles by mass are smaller than that size.) This particle size was used on the basis that it is the larger particles that cause more damage and wear. This is a reasonable assumption, but the authors believe that each size fraction contributes to the wear rate. However, the determination of these contributions is in itself a separate comprehensive study.

Other researchers[29,30] have shown that particles such as those constituting the size ranges smaller than the particle-

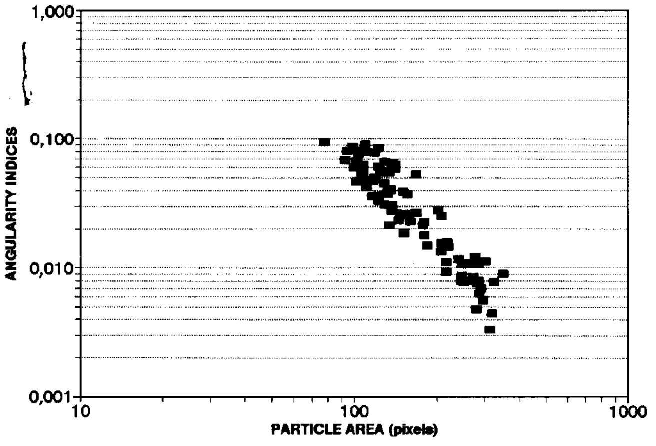

Figure 10—Relationship between angularity index and particle area for full plant tailings from President Steyn

Table IV

Angularity of the test materials (as calculated)

Type of solids	d_{90}	Angularity AI
Full-plant tailings:		
Vaal Reefs East	210,0	0,0160
President Steyn	192,8	0,0164
W. Deep Levels South	180,9	0,0143
Cycloned tailings:		
Elandsrand	260,0	0,0160
W. Deep Levels South	195,0	0,0150
Vaal Reefs South	215,0	0,0190
Vaal Reefs East	245,0	0,0200

size distribution of d_{90} cause up to 75 per cent less wear than those making up that particle size.

Some scatter is apparent in Figure 11. This could be due to a variation in the particle-size distribution of the sample used, an error in testing, or a material variation. It should be realized that this test procedure is also prone to errors because of the short testing periods. Both Figures 11 and 12 show an exponential trend of increasing wear rate with increasing particle size.

Finally, the results of Shannon and Sityebi[23], given in Table V, were plotted against the AI, as shown in Figure

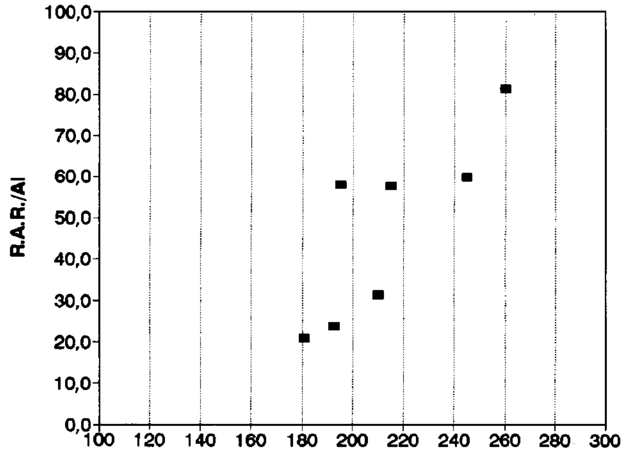

Figure 11—Jet-impact results (R.A.R.) normalized for particle sharpness (AI) versus particle-size distribution d_{90}

13. Their test procedure, which utilized a rotating pipe half filled with slurry, permitted the use in the present context of only the AI. This procedure results in the sliding of the particles over the pipe surface, involving no impingement of particles on the pipe surface. Therefore, no energy due to impacting is present in their system, such as occurs in actual pipelines.

CONCLUSIONS

The angularity index (AI), generated by use of a computer-based image-processing technique, is effective in characterizing differences in particle angularity. Trends of increasing wear rate with increasing particle size and particle sharpness were observed. The combination of the

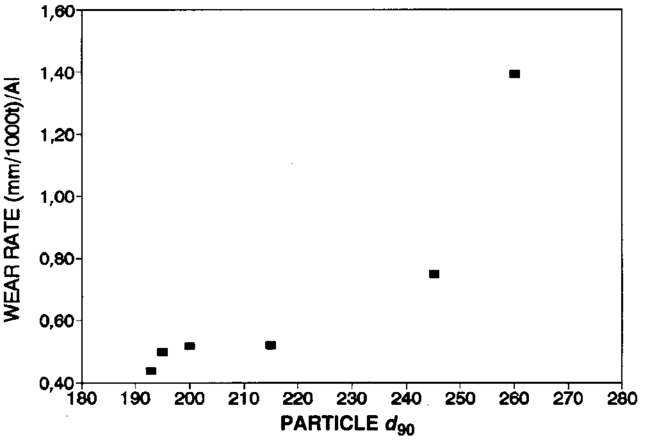

Figure 12—Pipe wear results normalized for particle sharpness (AI) versus particle-size distribution d_{90}

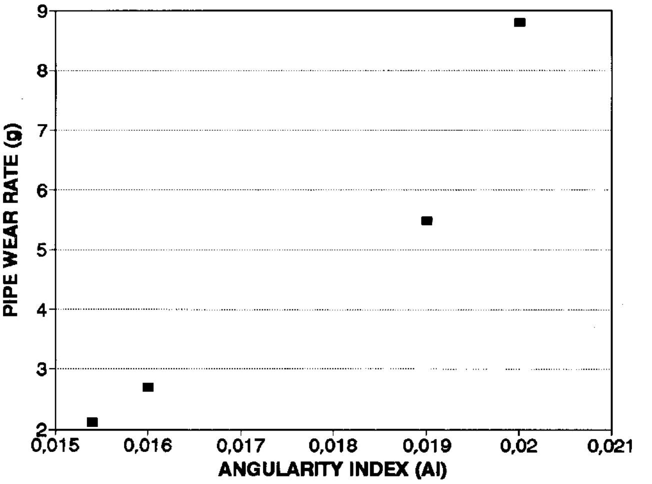

Figure 13—Pipe wear results versus angularity index (after Shannon and Sityebi[23])

Table V

Pipe wear loss after Shannon and Sityebi[23]

Type of solids	d_{90}	AI	Pipe loss g
Vaal Reefs East	150,9	0,020	0,003
Vaal Reefs South	146,1	0,019	0,002
Elandsrand	155,6	0,016	0,001
W. Deep Levels	146,0	0,015	0,0078

particle-size distribution typical for backfill, d_{90}, and the AI is effective in characterizing the variations in abrasivity between different sands used in backfill.

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Regeneration furnace*

Mintek has built their largest Minfurn direct resistive-heating furnace for the regeneration of activated carbon, a 6 t per day unit, for the carbon-in-pulp (CIP) plant at Leeudoorn Gold Mine.

Leeudoorn, a division of Gold Fields' Kloof Mining Company, had its official opening recently, and expects to attain a milling rate of 120 kt per month, and produce about 10 t of gold a year.

The Minfurn will assist the mine in containing costs, since it is capable of regenerating fouled eluted carbon in CIP plants to virtually virgin quality, with relatively low capital and operating costs.

The Minfurn is a vertical-tube furnace that is operated in a continuous mode utilizing direct resistive heating by means of an electrical current passed through the carbon, and has several advantages over conventional carbon-regeneration equipment.

- Because the entire volume of the furnace is utilized, the unit is smaller than rotary kilns and batch-operated furnaces of equivalent throughput.
- The Minfurn's utilization of energy is more efficient, since the highest temperature is reached in the carbon bed.
- The refractory walls of the furnace are resistant to high temperature and chemical attack.
- Maintenance costs are minimized as a result of the absence of moving parts in the system.
- The furnace is run on a unique patented control system, which does not rely on thermocouples.

* Issued by Mintek, Private Bag X3015, Randburg 2125.