J. S. Afr. Inst. Min. Metall., vol. 92, no. 6.
Jun. 1992. pp. 149–157

Combating pipeline wear—an advancing technology

by N.R. Steward* and A.J.S. Spearing†

SYNOPSIS

The increasing transportation of solids by pipeline, in South Africa and internationally, replacing the conventional transportation methods of rail, road, and conveyors, has resulted in much research into this area of solids transportation.

Pipeline wear continues to be an area of specific concern, since it constitutes a major cost during the life of a pipeline installation. Wear data from an accelerated wear test and actual pipeline tests are presented.

Trends in the performance of the pipeline materials tested are discussed, and possible solutions to the problem of pipeline wear are presented.

SAMEVATTING

Die toenemende vervoer van vaste stowwe deur pypleidings, wat die konvensionele vervoermetodes van spoorweë, paaie, en vervoerbande vervang, het in Suid-Afrika en internasionaal aanleiding gegee tot baie navorsing oor hierdie gebied van vervoer van vaste stowwe.

Slytasie van pypleidings was in die verlede rede tot groot kommer, en is dit vandag nog, omdat dit regdeur die hele gebruiksduur van 'n pypleidinginstallasie in groot mate tot koste bydra. Slytasiedata van 'n versnelde slytasietoets en werklike pypleidingstoetse word aangebied.

Tendense ten opsigte van die pypleidingmateriaal wat getoets is, word bespreek, en moontlike oplossings vir die probleem van pypleidingslytasie word aan die hand gedoen.

INTRODUCTION

The wear of pipelines transporting solids is of great importance to the designer and operator of hydrotransport systems. The reduction in pipewall thickness due to wear depends on many factors, as indicated by Table I. The tendency in the solids-handling industry has been to research and develop new and more wear-resistant materials in order to combat pipeline wear, rather than to gain an understanding of the performance and limitations of the existing materials: that is, materials development has tended to exclude practical evaluation.

The mechanical properties required for wear-resistant materials that are to be used for the transportation of slurries, or mixtures of solids and water, were traditionally considered to be hardness, strength, and toughness[2]. In this respect, slurry pipelines have historically been manufactured from cast irons and steels. Today, pipelines for the transportation of solids are still manufactured from alloy and heat-treated steels, i.e. stainless steel[3], induction hardened steel[4], Nihard alloy[5], and high-chromium white cast iron and cast irons (for coal transportation in both South Africa and the UK). These materials have, under varying conditions, been reported by many authors to have higher wear rates than rubbers, polyurethanes, and plastics[1,6–10].

The effectiveness of rubbers, polyurethanes, and plastics in combating slurry wear has been attributed to their elongation, tear strength, and resilience, or to their ability to absorb energy, deforming in the process and returning to their original shapes once the impacting object has left their surfaces[11–15].

Table I

Factors influencing pipeline wear (after Faddick[1])

Slurry Property		Pipeline	
Solid phase	Liquid phase	Property	Flow regime
Size	Viscosity	Composition	Velocity
Shape	Density	Hardness	Pressure
Sharpness		Elongation	
Density		Resilience	
Hardness		Orientation	
Concentration		Density or molecular mass	
Toughness			

However, the traditional design concept remains that, the harder the pipewall material, the less susceptible it is to slurry wear, and the manufacture of pipelines from high-alumina ceramics and martensitic steels bears testimony to this.

High-density polyethylene (HDPE), which has had success in the low-pressure transportation of slurry, has neither the hardness of steel nor the resilience of rubber. This success could arise from its resistance to chemical corrosion and limited resilience, and from its smooth inner surface, which reduces turbulence within the slurry owing to friction on the pipewall[16].

Also available on the market are composite materials that attempt to combine the properties of both the hard ceramics and the more resilient plastics, where the ceramic component, e.g. alumina balls, is contained within a plastic matrix. Theoretically, the hard ceramic component will be resistant to impacting particles while existing in a matrix of another material that will limit any crack growth and sustain minor deformation due to particle impact.

---

* Department of Surveying, University of Cape Town, Private Bag, Rondebosch, 7700 Cape Province.

† Gold and Uranium Division, Anglo American Corporation, P.O. Box 61587, Marshalltown, 2107 Transvaal.

© The South African Institute of Mining and Metallurgy, 1992. SA ISSN 0038-223X/3.00 + 0.00. Paper received October 1991; revised paper received February 1992.

The use of polyurethane has grown in the market place, especially as a material resistant to wear and impact, including its use as linings in slurry pipelines. The chemistry of polyurethanes is complex, enabling a vastly diverse range of products to be manufactured to combat almost any solids-transport environment. It is this characteristic of polyurethane that leads to its continuation as an advancing technology.

TEST APPARATUS

The apparatus used in the evaluation of pipeline materials is a closed-loop pipeline facility, which approximates actual pipeline conditions more accurately than any other laboratory method. The use of an actual field test would be ideal, but the monitoring of such an operation is difficult, and any error in the material selection is expensive, if not disastrous.

The closed-loop pipeline rig that was used in the present work is shown schematically in Figure 1 and consists of

- a slurry reservoir
- a centrifugal pump
- instrumentation
- the test pipeline
- heat-exchangers
- a jet-impact nozzle and bypass system
- a jet specimen holder.

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 4/3D centrifugal slurry-handling pump, with a rubber-lined volute and impeller. The velocity and concentration of the slurry are monitored by a magnetic flowmeter and calibrated weigh tank respectively.

The pipeline is constructed of polyvinyl chloride (PVC) with an inner diameter of 57 mm and a pressure rating of 900 kPa. Mild-steel heat-exchangers are used to maintain the temperature at approximately 32 °C.

A jet of slurry is generated at the exit orifice of the pipeline, where the diameter is smaller than that of the pipeline, that is, a nozzle at the point where the slurry is returned to the slurry reservoir. The specimens are kept in position below this slurry jet by means of a holder to which they are bolted.

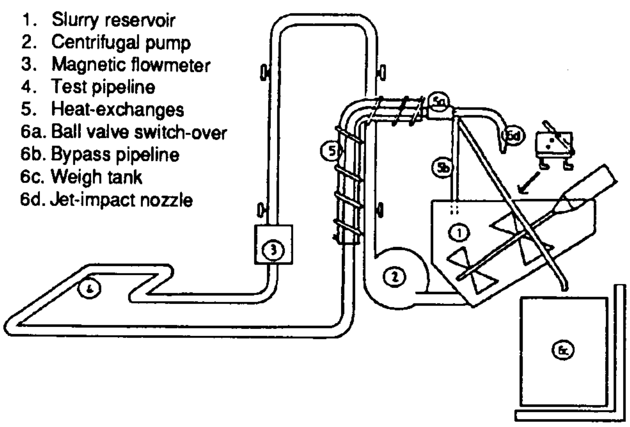


Figure 1—Diagram of closed-loop pipeline

TEST PROCEDURES

The two test procedures used in this work are discussed separately. The investigation of relative abrasivity required the use of a jet of slurry generated by the nozzle at the end of the return line, while the remainder of the research involved the use of the pipeline.

Jet-impact Procedure

The test conditions are summarized in Table II.

Table II

Parameters for the jet-impact tests

Nozzle velocity of slurry, m/s	16,5
Relative density of slurry	1,30
Temperature of slurry, °C	25
Impact angle of specimen, degree	20
Duration of specimen's exposure, min	108
Total duration of test, min	540

Five specimens of the materials under test were evaluated sequentially in a single test run of 540 minutes[17]. The initial exposure time to the slurry was 5 minutes per specimen. This results in a 20-minute interval between exposures of a specific specimen to the jet of slurry. The reason for these short initial exposures was to ensure that the specimens were subjected to the same particle parameters of sharpness, shape, and size. Particle degradation occurs rapidly, and long exposure times would result in subsequent specimens being eroded by slurry of entirely different characteristics.

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. At a slurry lifetime of 3 hours, where *slurry lifetime* is defined as the time that the slurry has been circulating in the rig from the start of the test, particle degradation, as shown by the decreasing wear rate of the specimen, had almost ceased. This implies that the slurry had reached its limit of decreasing particle size and particle rounding for the current test conditions of velocity and concentration. The total test time was 9 hours.

After each test run had been completed, the slurry was discarded and a new slurry was mixed in the slurry reservoir .

The wear rate of each specimen, in grams per hour, was calculated by the weighing of each specimen on an electronic balance before the test to an accuracy of 10 mg; after each subsequent exposure to the slurry jet, the specimen was dried and reweighed. Drying involved the removal of any excess water with a towel, followed by the removal of 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 slurry time.

Pipeline Procedure

The sections of test piping for evaluation were joined as shown in Figure 2. All three sections are of the same material, in this case a pipe of 0,2 per cent carbon welded steel. This method allows for the central section of the pipe to be accurately aligned with the lead-in and lead-out sections of 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. The slurry was then run at the required relative density and velocity through the closed-loop pipeline for 9 hours. After the test sections had been dismantled, the central section of each spool piece was weighed for material loss. The results were then converted to a reduction in wall thickness per ton of material transported.

THE PIPE MATERIALS TESTED

The materials tested fell into three categories: steels, elastomers, and polymers. All the materials tested under jet-impact conditions had the same dimensions of 150 by 75 by 10 mm. The three pipe sections of each material tested were all 500 mm in length with an inner diameter of approximately 50 mm. The inner diameters were all calculated to an accuracy of 0,05 mm. The names of the manufacturers and suppliers of the materials used are given in Addendum 1.

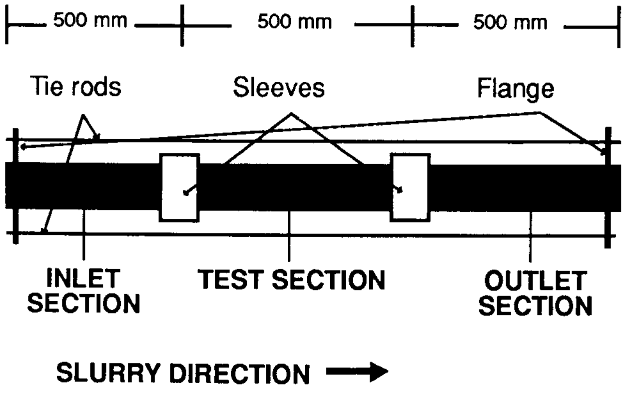
Mild Steel

The mild-steel pipe used in this research was standard SABS spec 62 medium-wall 50 NB seamed pipe. This pipe is specified to have an ultimate tensile strength of 320 to 460 MPa and a minimum elongation of 15 per cent.

For the accelerated jet-impact tests, plates of bright mild steel were used. Bright mild steel is the same in chemical composition as black mild steel, but is in the cold-rolled and annealed condition. This results in the surface having a bright, smooth finish. There are no differences between the mechanical properties of normal black mild (En 3A) and bright mild (En 3B) steel.

Heat-treated Steel

Two heat-treated steels were evaluated, designated HTS1 and HTS2. Both steels had been treated to have a martensitic layer on the inside of the pipe with a hardness of the order of 65 Rockwell C. The difference between the two was that HTSl had a mild-steel outer layer that was bonded to a hardened steel-alloy inner sleeve 5 mm thick. HTS2 was a 0,4 per cent carbon-steel pipe that was induction-hardened to produce a hardness profile across the wall thickness from the martensitic structure on the inside to the ferritic outside wall.



Pipeline od = 63 mm
Pipe id = 54 mm

Flanges = SABS 50 NB Table D
Sleeves machined from PVC, tight slip fit

Figure 2—Configuration of the pipeline test spool

High-density Polyethylene

Three high-density polyethylenes (HDPE) were evaluated: a standard HDPE tube (HDPE l), an HDPE tube enclosed within a steel pipe (HDPE 2) in order to increase the pressure rating of the HDPE pipe, and a cross-linked HDPE tube (HDPE 3). The first two materials had the same mechanical properties: a tensile strength of 22 MPa, an elongation in excess of 800 per cent at break, and a Shore D hardness of 60. The cross-linked HDPE had considerably different properties, and its inner surface finish was not as hydraulically smooth as that of HDPE 1 or 2.

Polyvinyl Chloride

This material was standard unplasticized PVC tube with a Rockwell A hardness of 111, a tensile strength of 45 MPa, and an elongation of 28 per cent.

Polyurethane

A number of polyurethanes were tested both as pipe and as plate specimens. The polyurethanes were differentiated by their hardnesses, that is, PU55, a hardness of 55 Shore A. Material hardness expressed by the Shore A scale is defined as the relative resistance of the material surface to indentation by an indenter of specified dimensions under a specified load.

All the polyurethanes tested were toluine diisocyanate (TDI) based with hybrid polyether prepolymers and MOCA cured.

The polyurethane was cast centrifugally into the pipe test pieces, and the plates were cast of solid polyurethane.

Rubber

The rubbers used as plate and pipe specimens were all vulcanized natural rubber with an average hardness of 40 Shore A. The rubber was hand-stitched and bonded to the inner surface of the pipe test specimen in an autoclave. The plates were manufactured by bonding of the rubber to a steel plate.

Basalt

The cast basalt was supplied in plates 25 mm thick and 300 by 300 mm. Plates were cut from this raw stock for the accelerated tests. Pipe pieces were not available at the time of testing owing to problems in the manufacture of small-bore piping.

Alumina

Two aluminas were evaluated as pipe specimens: a 97 per cent and a 94 per cent alumina. The pipe specimens were cast with an inner diameter of 50 mm and a length of 500 mm. The wall thickness of the pipe test specimens was approximately 10 mm. The evaluation of plate specimens of cast alumina are also reported in this paper.

High-chromium White Cast Iron

High-chromium white cast iron (HCWCI) was evaluated as plate specimens. This material had a 2,6 per cent content of carbon, a chromium content of 27 per cent, and was supplied with a hardness of 65 Rockwell C.

THE SOLIDS TESTED

The particle-size distributions of the solids evaluated in the described pipeline and jet-impact tests are given in Figures 3 to 7. The particle size of the coal dust tested was smaller than 70 μm.

The solids tested by other researchers and reported on in this paper include Olenogorsky iron ore (Figure 8), Turkish emery (Figure 9), and coarse sand (Figure 10).

RESULTS

Pipeline Tests

The pipeline results presented are all for a transport velocity of between 2,5 and 3,5 m/s. The results, in

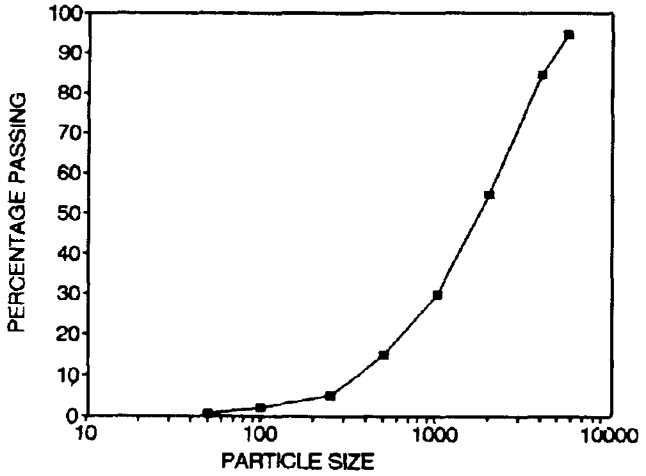


Figure 3—Particle-size distribution of the uranium tailings (in μm)

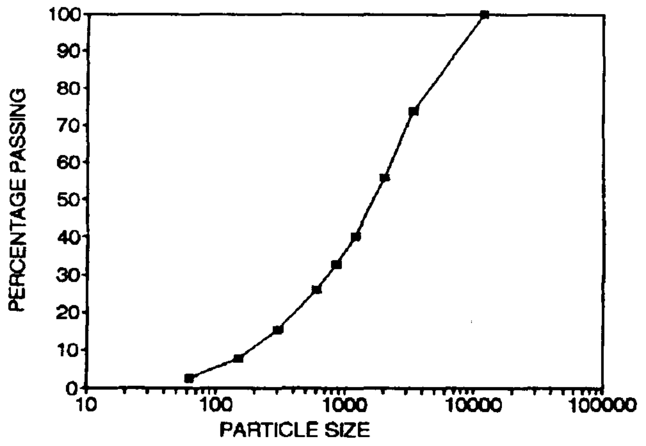


Figure 4—Particle-size distribution of the crushed gold-quartz ore (in μm)

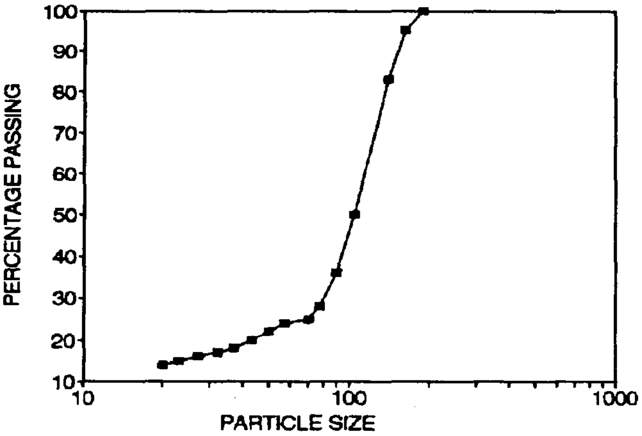


Figure 5—Particle-size distribution of the classified gold tailings (in μm)

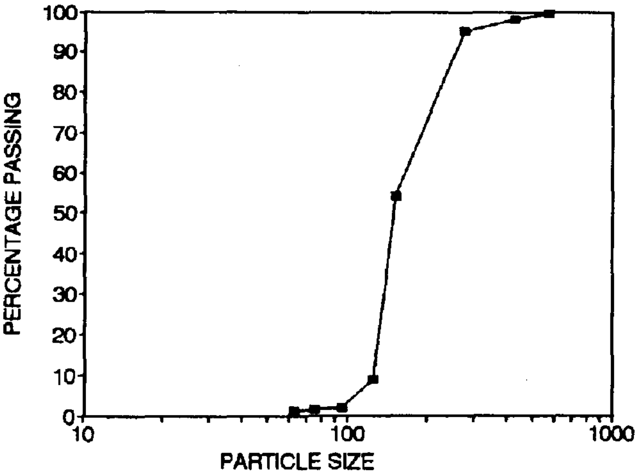


Figure 6—Particle-size distribution of the ilmenite (in μm)

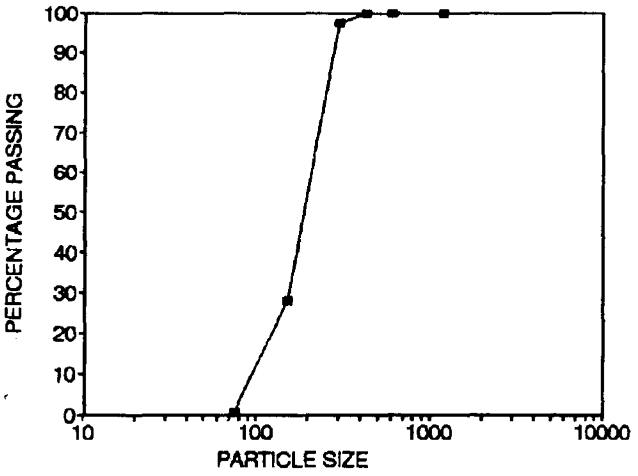


Figure 7—Particle-size distribution of the total gold tailings (in μm)

micrometres of pipewall lost per ton of solids transported, are given in Figures 11 to 15.

The results given in Figures 16, 17, and 18 were obtained by Hocke and Wilkinson[18], Jacobs and James[8], and Henday[19] respectively. Descriptions of the materials given by these authors are tabulated in Addendum 2.

Jet-impact Tests

These tests were carried out by the authors under the conditions described in Table II. The results, in Figures 19 to 23, are presented relative to mild steel, which has a performance of 1. A result greater than 1 indicates superior wear resistance.

DISCUSSION

These tests do not take corrosion into consideration where corrosion is considered to be an attack on the pipewall by a chemical or electrochemical reaction within its environment.

Corrosion has a significant impact upon steels, and to some degree alumina, leading to increased material loss[20].

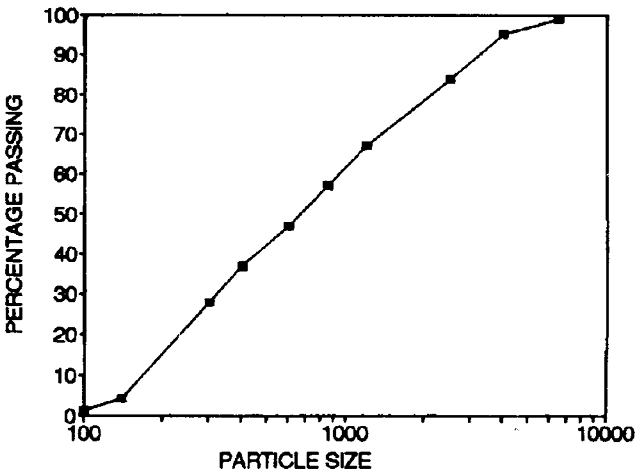


Figure 10—Particle-size distribution of coarse sand (in μm) after Henday[19]

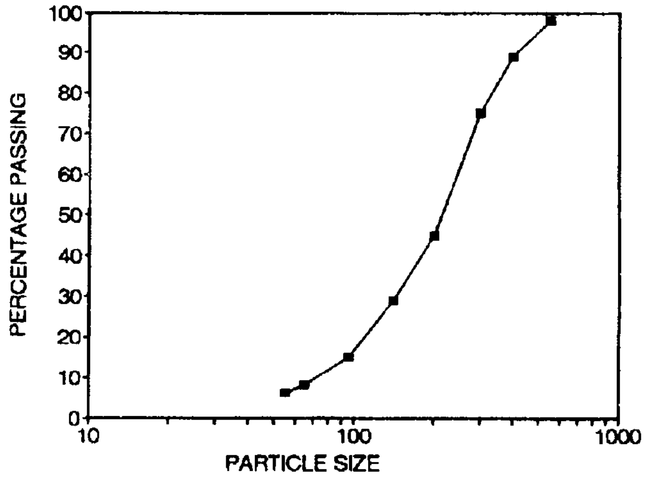


Figure 8—Particle-size distribution of Olenogorsky iron ore (in μm) after Hocke and Wilkinson[18]

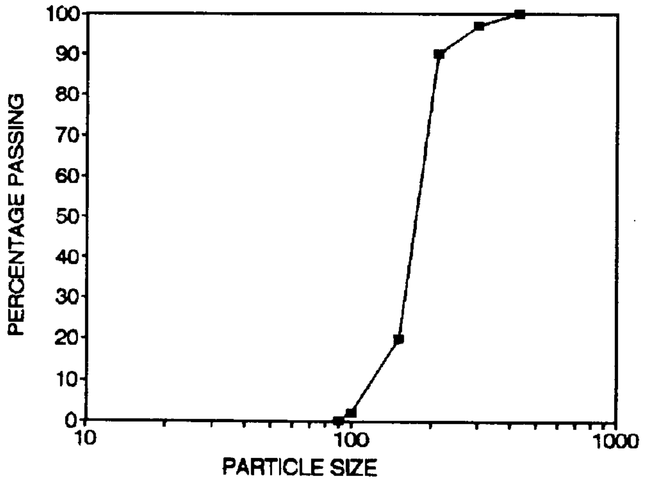


Figure 9—Particle-size distribution of Turkish emery (in μm) after Jacobs and James[8]

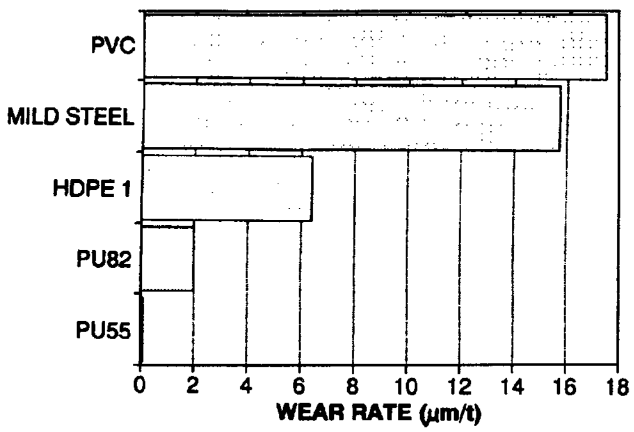


Figure 11—Uranium tailings
(50 NB pipe, 25% vol. concentration, 3,6 m/s velocity)

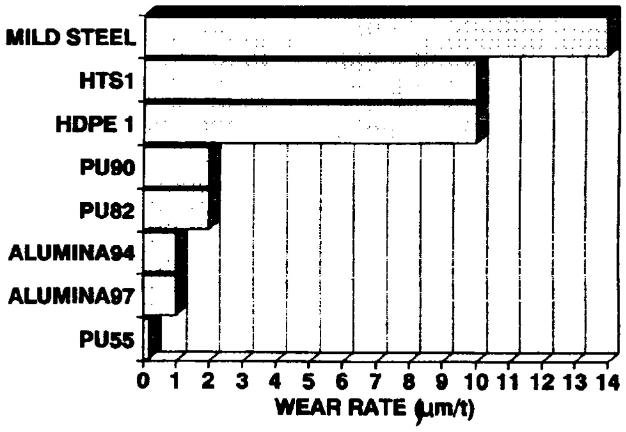


Figure 12—Crushed gold-quartz ore
(50 NB pipe, 25% vol. concentration, 3 m/s velocity)

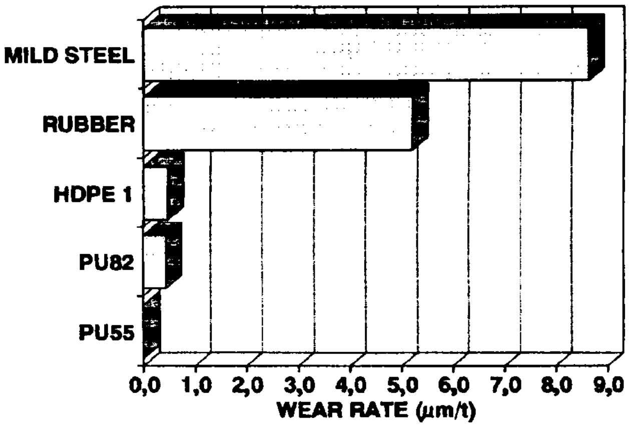


Figure 13—Ilmenite
(50 NB pipe, 25% vol. concentration, 2,6 m/s velocity)

In the

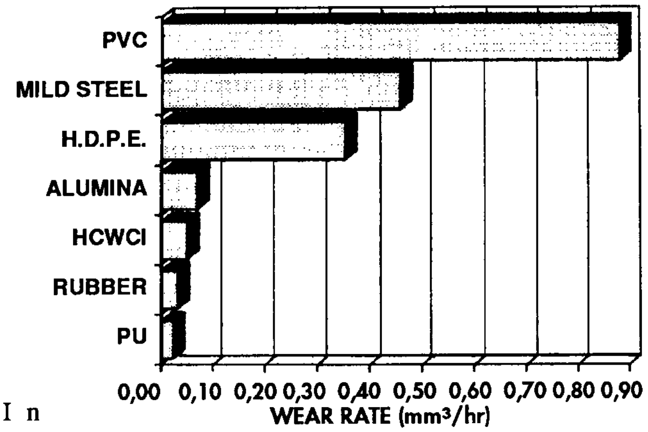


Figure 16—Olenogorsky iron ore[18]
(25 NB pipe, 18% vol. concentration, 3,7 m/s velocity)

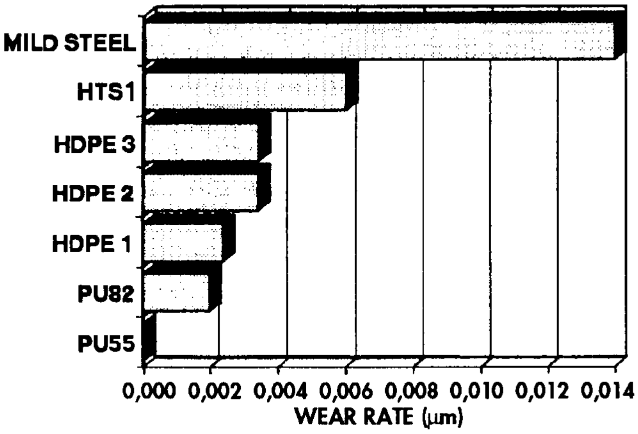


Figure 14—Classified gold tailings
(50 NB pipe, 42% vol. concentration, 3 m/s velocity)

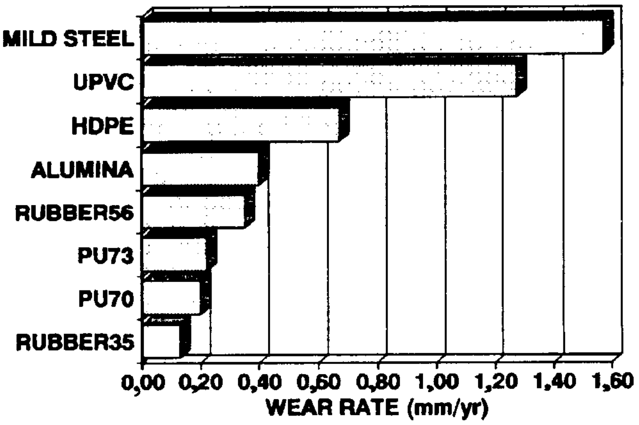


Figure 17—Turkish emery[8]
(38 NB pipe, 10% vol. concentration, 4 m/s velocity)

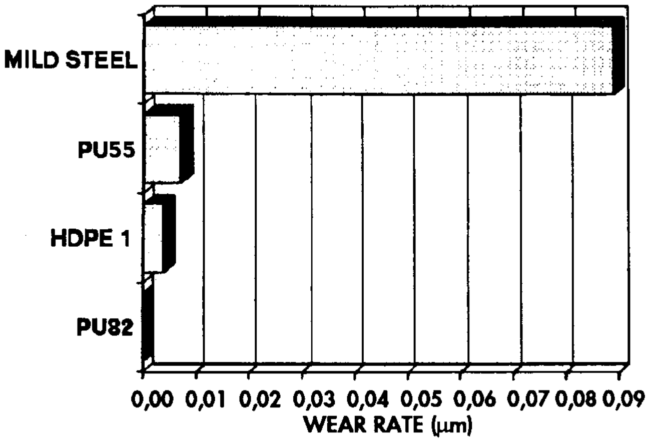


Figure 15—Coal dust
(50 NB pipe, 25% vol. concentration, 2,5 m/s velocity)

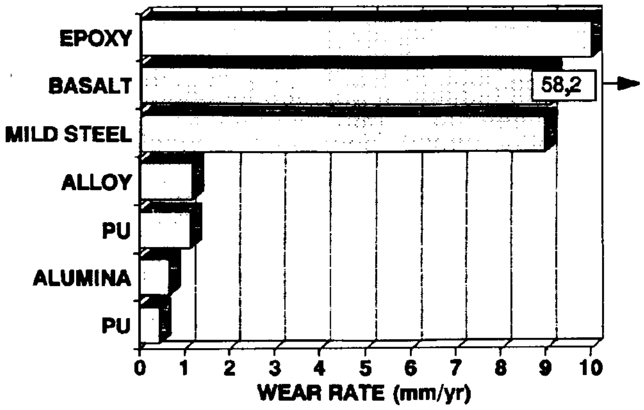


Figure 18—Coarse sand[19]
(160 NB pipe, 28% vol. concentration, 3,8 m/s velocity)

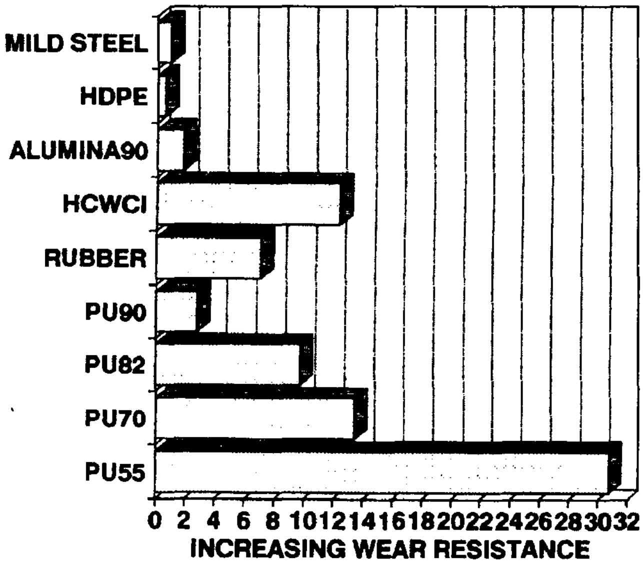


Figure 19—Jet-impact results for uranium tailings

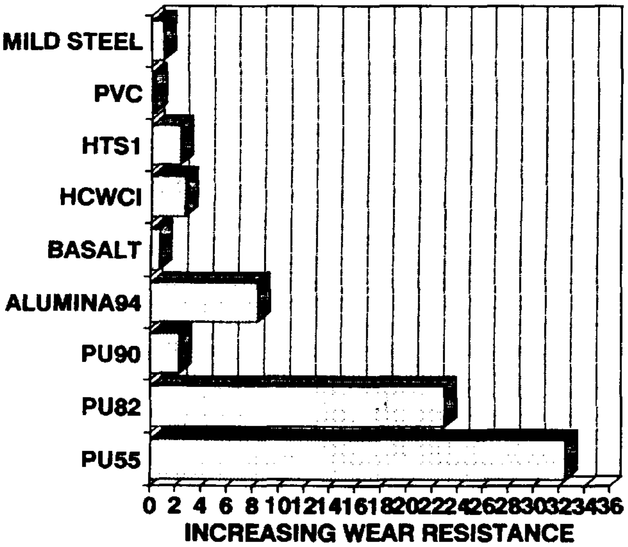


Figure 20—Jet-impact results for crushed gold-quartz ore

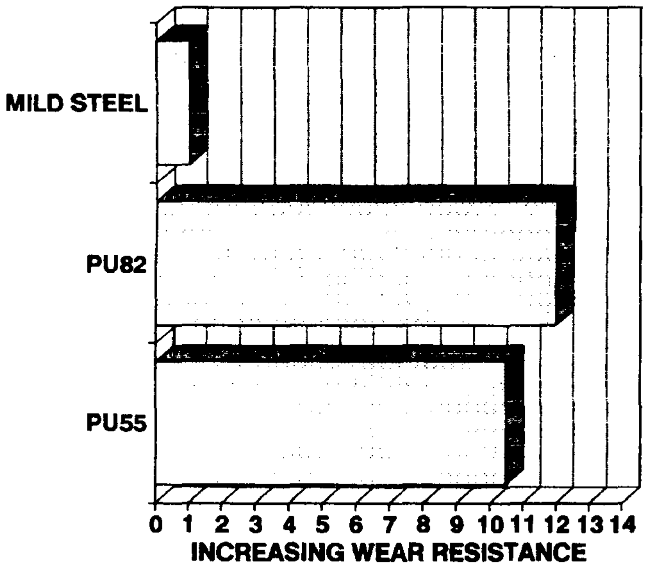


Figure 21—Jet-impact results for coal dust

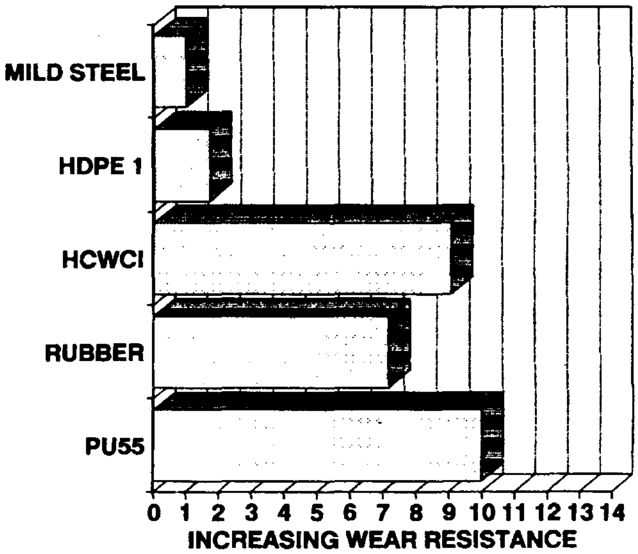


Figure 22—Jet-impact results for ilmenite

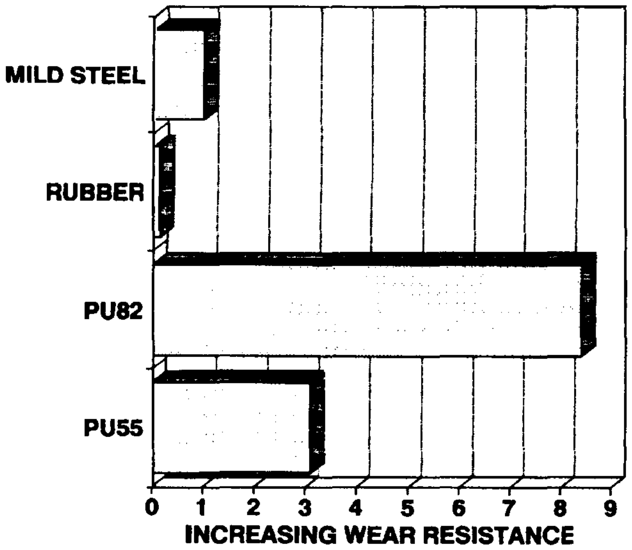


Figure 23—Jet-impact results for gold slimes

gold-mining industry, where backfill pipelines are flushed after use with highly oxygenated and acid water, corrosion constitutes a major problem.

Since plastics and elastomers are highly resistant to corrosion from chemical or electrochemical sources[7, 21, 22], the wear resistance of these materials under corrosive environments would increase relative to that of mild steels. HCWCI demonstrates considerable resistance to corrosion owing to its high chromium content.

The trends in the performance of the materials in both the accelerated jet-impact and pipeline tests are given in Table III. As the ranking of the materials used in the jet-impact tests relates to that in the pipeline tests, the jet-impact test can be regarded as an effective method for the selection of pipeline materials. However, this accelerated test method cannot replace actual pipeline tests when pipeline design data are required.

The main difference between the results from the two test procedures is the position of the plastic materials in the rankings. Under the jet-impact conditions, the plastics lost material at a greater rate than mild steel whereas, under pipeline conditions, the plastic materials performed better than mild-steel piping.

Under the impingement of high-velocity particles, the surface of the plastic material was quickly penetrated, providing sites for accelerated wear.

During the transportation of solids through pipelines, high-velocity jets of slurry still exist owing to turbulence[12]. However, they are short-lived, and only very fine particles are entrained, resulting in little energy being transferred onto the pipewall to cause material loss. The performance of HDPE 2, the steel-lined HDPE pipe, shows promise as a material for solids pipelines. The method of application requires the plastic pipe to be pulled through a mandril, reducing the pipe's outer diameter and making it easy to slip it into the steel pipe. The HDPE, having a shape 'memory', returns to its original outer diameter forming a tight friction fit with the steel pipe. The HDPE pipe is then temperature annealled to reduce the stresses in the pipe due to the lining process.

PU82 polyurethane, which is commercially available and has a tensile strength of 41 MPa, an elongation of 580 per cent, and a rebound resilience of 75 per cent, showed a greater or similar wear resistance to that of the other wear-resistant materials tested with the exception of PU55, which out-performs all the other materials evaluated.

In the case of the coal products, it is interesting that the harder polyurethane performs better than the softer PU55. The reason for this is not understood, other than that the very sharp glassy-phase solids present in the slurry may cut the softer PU55. PU82, however, has a greater tear strength than PU55 (35 kg/cm as against 12 kg/cm), which resists the removal of material due to the cutting action of particles. The resistance of polyurethane to wear has been attributed to its ability to absorb the energy transferred on impact by a fast-moving particle and to deform without failing. In this respect, it is similar to rubber.

PU55 came into being as a result of extensive research and development in the area of polyurethane mechanical properties versus wear rate[14]. As a polyether-based prepolymer hybrid, PU55 is manufactured by the combination of various hydrogen donors or polyols with the base diisocyanate. Usually, only one polyol is used to impart specific properties to the final polyurethane. By the combination of polyols, the best properties of each can be chosen, while those that are detrimental to the final product can be overridden. A more complete discussion is given by Bekker[23].

However, the use of polyurethane is not without its problems. Experience with polyurethane-lined pipes has shown that the surface preparation and application method is vital if the benefits of such pipes are to be realized. It is in this area that most problems occur: uneven thickness of lining due to bowed pipes, removal of lining due to poor bonding, and poor lining performance due either to incorrect polymer stoichiometry or insufficient curing. However, recent catastrophes involving underground fires and the danger of cyanide fumes from burning polyurethane have been over-played. The fact that polyurethane is cast into closed pipes should relieve even the sceptical regarding the dangers of burning.

Table III

Trends in the wear-resistance performance of the materials in the pipeline and jet-impact tests

Pipeline trend	Jet-impact trend	
Polyurethane	Polyurethane	**Decreasing wear resistance** ↓
Rubber	HCWCI	
HCWCI	Alumina	
Alumina	Martensitic steel	
HDPE	Mild steel	
Martensitic steel	HDPE	
Mild steel	Basalt	
Basalt	Polyvinyl chloride	
Polyvinyl chloride		

CONCLUSIONS

A ranking (Table III) in the wear resistance of pipeline materials for the transportation of solids is evident, even though the wear rates differ according to the solids transported and the transport parameters. The results show that steel piping lined with polyurethane or high-density polyethylene is the most promising wear-resistant material for such pipelines that have been evaluated to date.

ACKNOWLEDGEMENTS

The Department of Civil Engineering at the University of Cape Town is thanked for making the closed-loop pipeline available. The Technical and Development Services of the Gold and Uranium Division of the Anglo American Corporation is acknowledged for its financial and material contribution to this work.

REFERENCES

1. Faddik, R. Pipeline wear and particle attrition. Lecture F, Slurry pipelining course notes, BHRA, Fluid Engineering, Cranfield (UK), 1974.
2. Kruschov, M.M. Resistance of metals to wear by abrasion as related to hardness. *Proceedings of Conference on Lubrication and Wear.* London, Institute of Mechanical Engineers, 1957. pp. 655-659.
3. Kawashima, T., Yagi, T., Ise, T., Sato, E., Washimi, H., and Yokogawa, A. Wear of pipes for hydraulic transport of solids. 5th International Conference on the Hydraulic Transport of Solids in Pipes, HYDROTRANSPORT 5, Hanover (FRG), 1978. Paper E3.
4. James, L., and Ball, D.G. NASpipe performance report. Indutech, Sunderland (UK), Internal report, 1989.
5. Carter, A.M.F. Erosion, corrosion, and abrasion of material-handling systems in the mining industry. *J. S. Afr. Inst. Min. Metall.*, vol. 86, no. 7. Jul. 1986. pp.235-242.
6. Truscott, G.F. A literature survey on wear in pipelines. Cranfield (UK), BHRA, TN 1295, May 1975.
7. Sauermann, H.B. Pump and pipe wear. 8th International Conference on the Hydraulic Transport of Solids in Pipes, HYDROTRANSPORT 8, Johannesburg, 1982. Chap. 12.
8. Jacobs, B.E.A., and James, J.G. The wear rates of some abrasion resistant materials. 9th International Conference on the Hydraulic Transport of Solids in Pipes, HYDROTRANSPORT 9, Rome, 1984. Paper G3.
9. Murakami, S., Kawashima, T., Tsukahara, S., and Okada, T. Wear test of pipe linings for hydraulic transport of dam deposit. 7th International Conference on the Hydraulic Transport of Solids in Pipes, HYDROTRANSPORT 7, Sendai (Japan), 1980. Paper H2.
10. Ikeda, Y., Misawa, A., Minamiya, S., Owada, S., Kondo, I., and Kawashima, T. Development and wear test of new polyurethane

linepipe for slurry transportation. 10th International Conference on the Hydraulic Transport of Solids in Pipes, HYDROTRANSPORT 10, Innsbruck (Austria), 1986. pp. 247-258.

11. ABU-ISA, I.A., and JAYNES, C.B. Mechanism of abrasion of elastomers by small particle impacts. International Rubber Conference, IRC 86, Guteborg, Sweden. 1986.
12. EPHITHITE, H.J. Rubber lining—The soft option against abrasion. *Bulk Solids Handling*, vol. 5, no. 5. Oct. 1985. pp. 1041-1047.
13. STEWARD, N.R., and HECKROODT, R.O. Polyurethane as a wear resistant material in slurry handling applications. 11th International Conference on the Hydraulic Transport of Solids in Pipes, HYDROTRANSPORT 11, Stratford-upon-Avon (UK), 1988. Paper K3.
14. STEWARD, N.R. Predicting the wear of materials in hydraulic transport pipelines by accelerated test methods. 11th National Conference of the Plastics and Rubber Institute, Johannesburg, 1989.
15. RANSOM, D.W. Designing rubber compounds for wear resistance. SAIMM Colloquium, Mintek, Randburg (South Africa), 1985.
16. MELDT, R. Plastic pipes for the hydraulic transportation of solids. *Bulk Solids Handling*, vol. 1, no. 2. May 1981. pp. 307-312.
17. STEWARD, N.R. The wear of materials in hydraulic transport pipelines. M.Sc. thesis, University of Cape Town, 1988.
18. HOCKE, H., and WILKINSON, H.N. Testing abrasion resistance of slurry pipeline materials. *Tribology International*, 1978. pp. 289-294.
19. HENDAY, G. A comparison of commercial pipe materials intended for the hydraulic transport of solids. Cranfield (UK), BHRA project 3526, 1988.
20. MADSEN, B.W. Measurement of wear and corrosion rates using a novel slurry wear test. Corrosion 86, Houston (USA), NACE, 1986. Paper 235.
21. GALKA, R., and YATES, A.P.J. *Pipe protection—A review of current practice*. Cranfield (UK), Paint Research Association, BHRA Fluid Engineering, 1984.
22. GARRETT, C., BURKES, D., and BARACH, J. PUs in the pipeline, increasing resistance to slurry. 6th International Conference on the Internal and External Protection of Pipes, Nice (France), 1985.
23. BEKKER, B. Urethane prepolymer hybrids. 9th National Conference of the Plastics and Rubber Institute, Johannesburg, 1987.

ADDENDUM 1: MANUFACTURERS AND SUPPLIERS

The names of the manufacturers and suppliers of the materials used in the present tests are given below.

Mild steel	Stewart & Lloyds, Cape Town, SA
Bright mild steel	Bonuskor steel, Beaconvale, Parow, SA
HTS1	Solidresist, Rohrtechnik gmbh, Germany
HTS2	NASpipe, IMS, Sandton, Johannesburg, SA
High-density polyethylene	Mega Pipe, Rosslyn, Pretoria, SA
Polyvinyl chloride	Main Industries, Cape Town, SA
Polyurethane	National Urethane Industries, Spartan, Kempton Park, SA
Rubber	Richards Bay Retreaders, Richards Bay, SA
Basalt	Multotec Cyclones, Spartan, Kempton Park, SA
Alumina	Moh 9
High-chromium white cast iron	MITAK, Alrode, Johannesburg, SA

ADDENDUM 2: MATERIALS USED BY OTHER RESEARCHERS

The following lists describe the materials tested by the other authors reported on in this paper.

Hocke and Wilkinson[18] (1978)

PVC	RS60 'Vylastic'
Mild steel	0,20 % carbon 0,06 % phosphorus 0,06 % sulphur 0,8 % manganese
High-density polyethylene	
Alumina	'Deranox' 97,5 % Al_2O_3
High-chromium white cast iron	2,3 % carbon 0,5 % silicon 0,10 % sulphur 0,04 % phosphorus 1,75 % manganese 20,0 % chromium 0,40 % nickel 2,2 % molybdenum
Rubber	BTR rubber
Polyurethane	Scandura PU50

Jacobs and James[8] (1984)

Mild steel	ASTM A106
PVC	Unplasticized PVC
High-density polyethylene	
Alumina	'Deranox' 97,5 % Al_2O_3
Rubber 56	Dunlop hardness 56, Lupke resilience 32
PU73	Dunlop hardness 73, Lupke resilience 45
PU70	Dunlop hardness 70, Lupke resilience 50
Rubber 35	Dunlop hardness 35, Lupke resilience 60

Henday[19] (1988)

Mild steel	BS 3601
HTS	Induction-hardened steel-tube NASpipe
PU1	Cast polyether polyurethane
Alumina	Ms-grade alumina ceramic
PU2	Cast TDI polyether polyurethane

Mintek wins technology award*

Mintek has been awarded top honours in the mining category of the Technology Top 100 programme organized by The South African Engineering Association (SAVI) and *Engineering Week*. Dr Peter Jochens, Mintek's Deputy President, accepted the award from Mr Derek Keys, Minister of Trade and Industry and Economic Co-ordination at a banquet held at the Carlton Hotel.

The Technology Top 100 programme is an initiative to promote awareness of the technological prowess of South African companies, and to ensure comprehensive overseas coverage of their technology, thereby encouraging joint ventures with foreign concerns. Awards are presented each year to winners in six categories: chemical, electronics, energy, machinery, mining, and research and development.

The adjudicating panel, which is representative of the upper echelons of the country's scientific, engineering, industrial, and business disciplines, evaluates participating companies on the following criteria: commitment to research and development, innovation, number of patents registered, royalties received from patents, exports, manpower ratios of technically trained people to other staff, capital investment, and support of engineering education at tertiary institutions.

Out of the 61 applicant companies in the programme in 1991, 53 qualified for inclusion, and overviews of their achievements, together with those of the six winners in the various categories, are published in a booklet that is expected to become an annual definitive guide for potential foreign investors.

---

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

Mechanical engineering doctorates break new ground*

Theses recently completed by Ph.D. candidates in the School of Mechanical Engineering at the University of the Witwatersrand have made important headway in both mine-cooling technology and the transportation of slurries.

MINE COOLING

A thesis entitled 'Pneumatic conveying of ice particles through mine-shaft pipelines' is the work of Professor John Sheer, who has recently joined the academic staff of the School of Mechanical Engineering. Arising from work carried out jointly by COMRO and Rand Mines (Mining & Services) Ltd, this is the first comprehensive scientific study on this topic to be published. Using a pilot conveying installation, Professor Sheer shows that it is feasible, provided that certain precautions are taken, to convey ice underground through pipelines at high flowrates to cool the working environments in very deep mines.

The two largest ice-production facilities in the world have been commissioned on mines in the Rand Mines Group for this purpose.

Guidelines are provided in the thesis for use in the design of ice-conveying pipeline systems, including equations for the prediction of the pressure gradients along the main pipeline sections.

TRANSPORT OF SLURRIES

The second Ph.D. thesis, that by Cornelius Verkerk, aims to characterize the transportation of various slurries in the 'turbulent medium phase slurry and/or paste flow regime'. It identifies important characteristics of local materials relevant to the design of slurry systems, and gives a good indication of the operational bands required for the assessment of slurry-transport systems.

The effects of particle size and its distribution for various slurry concentrations on the viscous behaviour of the slurry were studied in detail, and the rheological characteristics of the slurries determined in laboratory tests were related to their behaviour in experimental closed-loop systems. The materials studied included quartz-based mine tailings, pulverized fuel ash, boiler-bottom ash, washing-plant coal slurries, discard coal, and hematite tailings.

The research constitutes a major contribution to the understanding of the characteristics of slurry conveyance and, hence, to the effective design of such systems.

---

* Issued by Lynne Hancock Communications, P. O. Box 3712, Honeydew, 2040 Transvaal.