bulk solids handling Volume 3, Number 1, March 1983

Fundamental and Applied Research in Hydraulic Transportation at the CSIR, Pretoria, South Africa

H.B. Sauermann, South Africa

Summary

This article outlines the type of work on hydraulic transportation of solids which has been and is being carried out by the National Mechanical Engineering Research Institute at Pretoria. Special emphasis is placed on handling mineral slurries, since the mining industry plays an important part in the South African economy.

1. Introduction

In a country such as South Africa where many types of minerals are available and distances are great, hydraulic transportation of solids in pipelines may become the most economical means of bulk transportation. For this reason, the National Mechanical Engineering Research Institute (NMERI) of the Council for Scientific and Industrial Research (CSIR) established, some ten years ago, test facilities for fundamental and applied research in this field. These facilities have been used for a number of important investigations for industry.

2. Test Facilities

The test facilities at the NMERI consist of:

- a 38/50 mm diameter test loop with a test length of 10 m;
- a 100 mm diameter test loop with a test length of 25 m which is particularly suitable for coarse material — the material is introduced into the pipeline from a pressure vessel after the pump;
- a test loop consisting of 100, 200 and 250 mm pipes with a 50 m long test section in each; these loops are equipped with a data acquisition system by means of which the computerized results are processed and plotted in graph form; at the 180° return bend of the 100 mm diameter test loop, a 7 m long transparent section can be inclined at various angles to determine the maximum slope under which the slurry can be pumped;
- rotary and capillary tube viscometers for feasibility pumping studies using relatively fine material (< 50 μm);
- a pump wear test rig; and
- a pipe wear test rig.

3. Industrial Investigations

Major investigations undertaken for industry using these test facilities have included the transportation of the following:

- gold slimes (seven types);
- sand tailings (two types);
- coal slurries (two types);
- kimberlite ores (two types);
- heavy minerals;
- tin waste; and
- diamond concentrate.

These investigations resulted in basic design data for the construction of several slurry pipelines, the most notable being that for the East Rand Gold and Uranium Company (ERGO). In this scheme, 19 slimes dams on the East Rand are earmarked for retreatment to extract residual quantities of gold, uranium and pyrite. To make this scheme viable, 20 million tons of slimes per annum must be treated.

Specially built remote controlled, and hydraulically operated water cannons direct jets of water under high pressure — 2.5 MPa — at the dam walls. A battery of three cannons 'monitor' each of the three dams being worked and every hour the combined cannons use 2,500 m^3 of water to slurry 2,100 tons of solids which are gravity-fed to the adjacent pumping station. After screening the slurry is pumped through large pipes to the flotation plant at the ERGO complex some 10 or more kilometres away. Three slimes dams are monitored simultaneously, with two main pipes serving each dam; one pipe carrying water for the monitoring guns and the other carrying the slurry (see Fig. 1).

The pumping tests were undertaken in the 100, 200 and 250 mm diameter pipe test loops (see Fig. 2) on two different slimes samples. By means of an extrapolation method [1] especially developed for this purpose, the test results were scaled-up to 450 mm diameter pipes, the size of the slurry pipelines.

A paper describing the practical experience in pumping these slurries at ERGO [2] was presented at the 8th International Conference on the Hydraulic Transport of Solids in Pipes organized by the British Hydromechanics Research Association (BHRA) in conjunction with the CSIR and S.A. Engineering Institutions. This conference, which was held at the Rand Afrikaans University, took place during August 1982. According to this paper 'the parameters determined by the CSIR were found to be repeated in practice'.

Fig. 1: Slurry pipelines and return water pipelines with acid plant and storage tanks in the background.

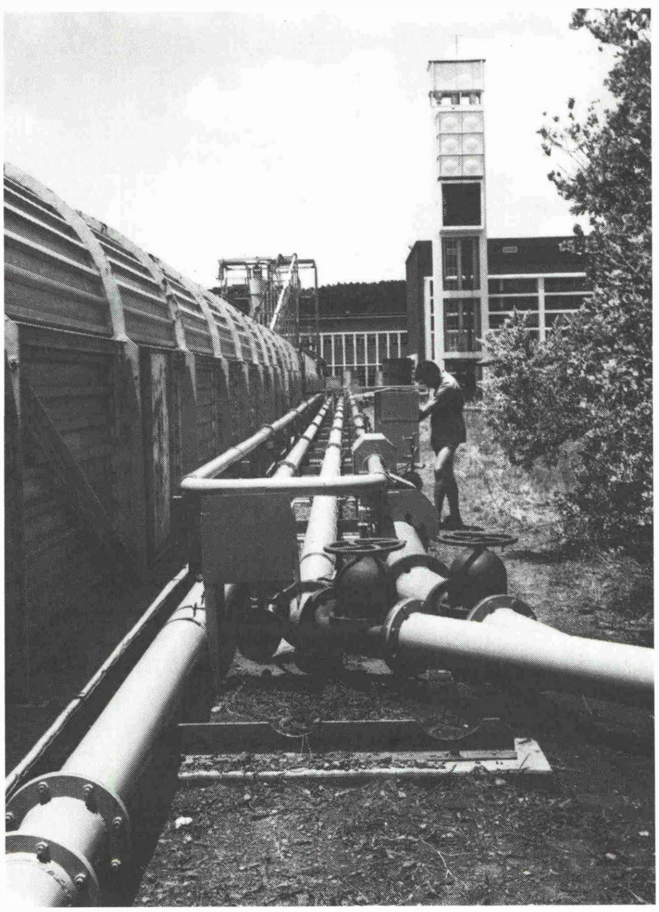


Fig. 2: The 100, 200 and 250 mm diameter slurry test loops

In a paper titled "*Slurry for Sale*" which was also presented at this conference [3], the practical experience of pumping phosphate in a 2.3 km long 175 mm diameter pipeline at Foskor (Phalaborwa) was described. The loop investigation for this slurry pumping scheme was undertaken by the NMERI in the 40 and 100 mm diameter pipe loops. The value of such testing is endorsed in the paper — 'Wherever possible, the use of practical loop testing is advocated and is considered to be invaluable for the design of slurry pumping installations. The cost of the tests is minimal when compared with the overall economy of the design'.

4. Fundamental Research

4.1 Hydraulic Transportation of Coarse Solids

In addition to contract investigations, the Fluid Mechanics Division of the NMERI undertakes fundamental research in the field of hydraulic transportation of solids. The particle diameters of the solids at present transported in long-distance slurry pipelines are relatively small. In many cases, small particle sizes are necessary for the beneficiation of mineral processes and therefore grinding costs should not be added to the cost of hydraulic transportation. Nevertheless, any designer of hydraulic transportation pipelines would prefer the pumping of coarser material if the same solids throughput could be pumped at the same energy requirement as small particle material. This would eliminate the high costs of dewatering materials at the pipeline terminal. There are also some cases where material must be as large as a few millimetres in diameter for processing, e.g. coking coal.

There appears to be a general tendency in the field of hydraulic transportation of solids towards pumping material of larger particle size. It is believed that many more hydraulic transportation pipelines would be designed and constructed if coarser material, i.e., in the millimetre size range, could be transported economically.

From a literature survey in respect of larger particle transportation, it appeared that transport through pipes of non-circular cross-section and in particular through a segmented pipe seemed attractive [4]. A segmented pipe is a circular pipe with a plate welded horizontally across the inner perimeter in the lower part of the pipe giving it a flat bed (see Fig. 3).

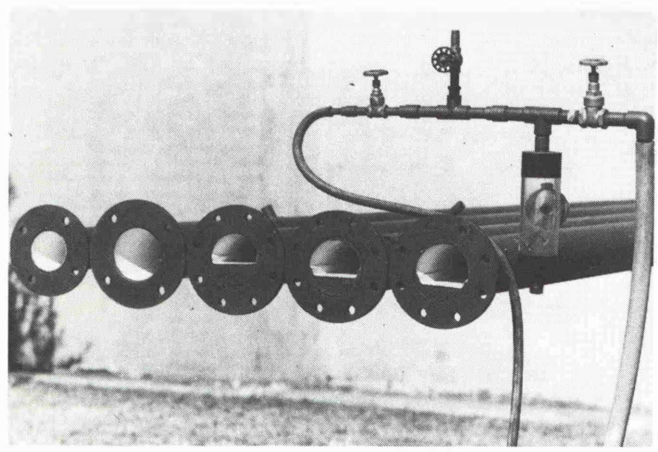


Fig. 3: Circular and segmented pipes

A typical concentration distribution for coarse material shows that the largest concentration of this material is at the bottom of the pipe. Because of the shape of a circular pipe, the concentration of coarse material is compressed into a very small area whereas the plate fixed inside a pipe provides a wider area onto which the coarse material will sink where it can be transported more easily (see Fig. 4).

Pipes with an elliptical or rectangular cross-section would, of course, also provide a wide area for the large concentration. The disadvantage of all non-circular cross-sections is that the stresses are greater in the pipe wall and therefore thicker

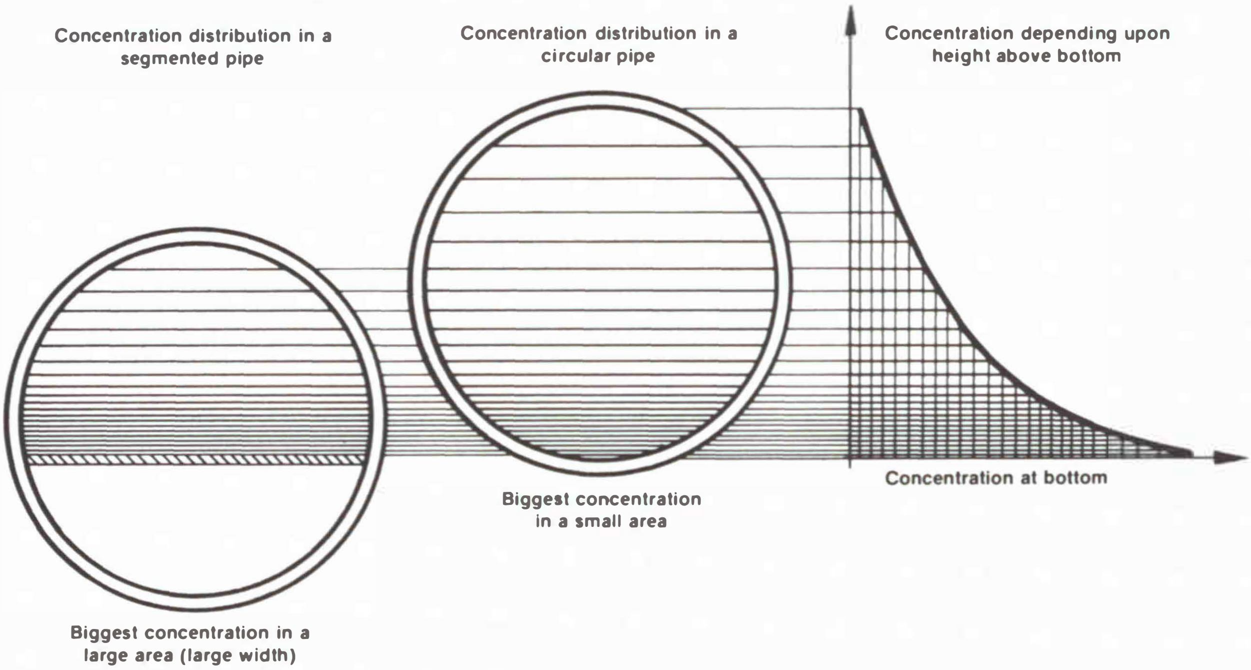


Fig. 4: Distribution of concentrations in pipes

pipe walls are required. If provision is made in the segmented pipe for the static pressure beneath the segmenting plate to be the same as that above the plate, i.e., in the area of the slurry flow, the plate is subjected only to the slurry flow and not to the inside pressure of the pipeline. Pressure equalization can simply be obtained with the provision of small holes in the segmenting plate.

For the tests, a pipe with a nominal diameter of 100 mm was selected [5]. Segmenting plates were placed at three different heights chosen around the level $h/D = 0.33$ (h is height of segmenting plate above pipe bottom, D is pipe diameter). As the flow cross-section of the pipe with the segmenting plate in its highest position was approximately the same as that of a circular pipe with a nominal diameter of 75 mm, a series of tests with the latter pipe were carried out in order to compare a segmented pipe with a circular pipe, both of which had the same flow area.

Four different samples of sands with particle diameters ranging from 1 mm to 5 mm and four samples of anthracites with particle diameters between 5 mm and 10 mm were tested in five different pipes. Two were normal circular pipes with diameters of 75 mm and 100 mm respectively and three were segmented pipes (see Fig. 3).

It was discovered that the larger and denser the solids, the less is the specific energy required for the same throughput of solids through a segmented pipe compared with a circular pipe. For the 5 mm sand, the reduction in specific energy for the same solids throughput was about 35% less in the segmented pipe than in the circular pipe. The optimum position of the segmenting plate was at about $h/D = 0.37$. Comparing the segmented pipe and circular pipe with the same cross-sectional area, a reduction in specific energy of up to 20% in the segmented pipe for the same solids throughput was established. The tests have shown without doubt that pipe geometry has an important influence on the hydraulic transportation of coarse solids.

4.2 Refilling Worked-Out Mine Sections

The disposal of gold slimes tailings from South African mines presents an ever-increasing problem to the industry. The building of new gold slimes dams and their necessary maintenance is expensive and an alternative has been sought so that the tailings can be disposed of more cheaply.

One solution is to pump the slimes back into the worked-out sections of the mines. If they can be pumped back at high concentration by mass (approximately 75% to 77%), i.e., a very thick slurry, this will not only solve the disposal problem but will have the added advantage of using the gold slimes to act as a solid pillar to support the hanging wall of the worked-out stopes. Because of pressure from above, the hanging wall gradually sinks and the thick slurry is able to support this load. A large number of small earth tremors occurs in the gold mining areas of South Africa and it is suspected that many of these are caused by the collapsing of hanging walls. To use the waste gold slimes to minimize these tremors would be an added advantage.

The problem with pumping slimes with high mass concentrations of between 75% and 77% is that at present no pumps are available which are capable of pumping a highly concentrated gold slimes slurry more than 200 m. To enable such material to be pumped, various additives which would reduce the viscosity and yield stress of the slurry were investigated [6].

To meet both the criteria of having a more liquid slurry to move along the pipe and a thicker material for placing in the worked-out stopes, it is necessary first to thin the slurry and then to neutralize the effect of the additive at the end of the pipeline so that the slurry is returned to its original state.

The addition of sodium tripolyphosphate reduced yield stress to virtually zero and also considerably reduced the viscosity of the slurry. Consequently a substance which would neutralize the effect of this additive and return the slurry to the required thickness when needed had to be found. By introducing calcium hydroxide the slurry reverted to its original thickness.

The above research was mainly undertaken in a rotary viscometer. Tests for thinning the slurry with the addition of sodium tripolyphosphate were also undertaken in a 40 mm diameter pipeline with a mass concentration of 76 % and in a 200 mm diameter pipeline with a mass concentration of 70 % [7]. In the latter case the pressure gradient of 970 kPa/km was reduced to 300 kPa/km at a velocity of 1.8 m/s or a reduction of about 70 % when 0.15 % of sodium tripolyphosphate was added.

The development process involving the thinning and re-thickening of the slurry is now being patented and all rights in the process have been assigned to the South African Inventions Development Corporation (SAIDCOR).

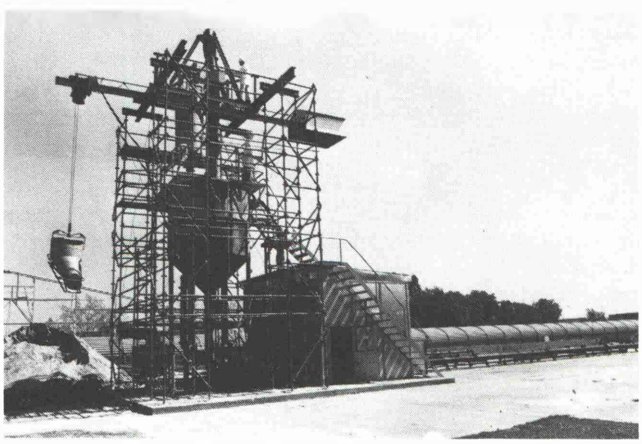
4.3 Pump and Pipe Wear

The useful life of a slurry pipeline depends largely on the wear rate in pumps and pipes. Deterioration of pipes can be very high with the transportation of certain materials. The potential life of components is accordingly a most important economic consideration when slurry systems are designed.

Pump and pipe wear in hydraulic transportation pipelines depends upon many parameters, some of which are extremely sensitive to small deviations in operational conditions. Their influence can be determined either on site or in the laboratory. Prototype tests on site are however difficult, expensive and time-consuming. Pump and pipe wear test rigs have accordingly been designed and constructed by the NMERI.

In the case of pump wear, the shape and material of the impeller as well as the material of the pump lining is being investigated by pumping certain slurries for many hundreds of hours through the system (see Fig. 5). Since the continuous circulation of slurry results in an increase in slurry temperature, heat exchanger pipes are provided to keep the slurry at an acceptable temperature. If the size distribution of the solids changes considerably after a few hundred hours a new batch of solids is used. The amount of wear of the impeller and the pump lining is determined by the measurement of the thickness and the loss of mass.

Fig. 5: Pump wear test rig



Regarding the pipe wear test rig, the influence of parameters such as three pipe wall materials, two solids at two concentrations and two velocities can be studied simultaneously.

This article gives an indication of the type of work on hydraulic transportation of solids which has been and is being carried out by the NMERI. With its ongoing programme of research, the NMERI hopes to be able to solve many more problems in this field and in this way, contribute towards a better understanding of this complex subject. The mining industry in particular, which plays such an important part in the South African economy, will benefit from this work as will the overall economy of the country.

References

[1] Webster, I.W. and Sauermann, H.B., "Pressure gradient scale-up methods for slurry pipelines", S.A. Mech. Eng., Vol. 28, August 1978

[2] Sabbagha, C.M., "Practical experiences in pumping slurries at ERGO", Paper A1, 8th International Conference on the Hydraulic Transport of Solids in Pipes, Johannesburg, South Africa. Published by BHRA Fluid Engineering, Cranfield, Bedford, England (August 25—27, 1982)

[3] Nordin, M., "Slurry for sale", Paper F2, 8th International Conference on the Hydraulic Transport of Solids in Pipes, Johannesburg, South Africa. Published by BHRA Fluid Engineering, Cranfield, Bedford, England (August 25—27, 1982)

[4] Führböter, A., "Über die Förderung von Sand-Wasser-Gemischen in Rohrleitungen", Mitteilungen des Franzius Institut für Grund- und Wasserbau der Technischen Hochschule, Hannover, Heft 19, 1961

[5] Sauermann, H.B., "Hydraulic transport of coarse solids in circular and segmented pipes", Proceedings of the Seventh International Technical Conference on Slurry Transportation, Lake Tahoe, Nevada, USA, March 1982

[6] Horsley, R.R., "Viscometer and pipe loop tests on gold slimes slurry at very high concentrations by weight, with and without additives", Paper H1, 8th International Conference on the Hydraulic Transport of Solids in Pipes, Johannesburg, South Africa. Published by BHRA Fluid Engineering, Cranfield, Bedford, England (August 25—27, 1982)

[7] Sauermann, H.B., "The influence of particle diameter on the pressure gradients of gold slimes pumping", Paper E1, 8th International Conference on the Hydraulic Transport of Solids in Pipes, Johannesburg, South Africa. Published by BHRA Fluid Engineering, Cranfield, Bedford, England (August 25—27, 1982)