Lateral hydraulic transportation of comminuted reef and waste in future concentrated mining operations

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Synopsis

The paper reviews the results to date of an integrated research programme currently being conducted by CSIR Mining Technology, aimed at impacting significantly on concentrated mining with face advance rates of up to 20 times faster than presently achieved.

Consideration is given to the interplay between innovative technologies for continuous non-explosive mining or rock comminution underground and lateral hydraulic transportation in cross cuts, haulages and eventually hydrohoisting.

Novel technologies for underground comminution of reef and development waste and an innovative pumping system suitable for the hydraulic transportation of coarse comminuted rock are reviewed. Emphasis is placed on South African gold mine reef and waste samples comminuted by electric shock wave comminution technology.

The innovative TORE® pump system appears to be well suited for the successful hydraulic transportation of rock, produced by electric shock wave comminution, at solids concentrations between 45 % and 67 % by mass.

Introduction

Continuous concentrated mining, with face advance rates of up to 20 times faster than presently achieved, may be the single most important criterion to ensure the economic survival of deep level mining. Ideally, to facilitate continuous concentrated mining, a non-explosive mining method that generates a hydraulically transportable rock directly at the face, would be desirable. Otherwise, mining in combination with supplementary underground comminution, that will enable lateral hydraulic transportation virtually from the stopes in pipelines along the cross cuts and haulages, and eventually hydrohoisting in the shafts is considered.

It may be argued that substantial R&D on the potential of hydraulic transportation of underground comminuted rock has been done before, without much success. What has changed now, is that CSIR Mining Technology have identified innovative technologies for underground comminution of reef and waste rock, and novel pumping systems that offer a much greater potential to successful implementation than those considered before.

The concept, however, critically relies on the selection of suitable technologies. The method and degree of comminution of rock underground must produce acceptable particle size distributions even under variable rock conditions, to ensure trouble-free hydraulic transportation of the rock from the underground workings to surface.

This paper describes some of the recent results as they relate to the hydraulic transportation of comminuted rock, either as reef for hoisting or as backfill for underground support.

CSIR Mining Technology's integrated research programme

Although this paper deals specifically with underground comminution and hydraulic transportation aspects in future deep level mining, it must be borne in mind that promising non-explosive primary rock breaking methods are also being investigated by CSIR Mining Technology. These may well be integrated with the hydraulic transportation technologies under investigation, directly at the stopes.

A particularly exciting possibility is based on mining by electric spark erosion technology for instance. If this is eventually developed, pumping reef directly from the stope face to surface with no other intermediary transfer requirements becomes a real possibility.

Another element of the integrated research programme is the minimisation of development waste transportation to surface, utilising as much development waste as possible for the production of high performance backfill for the provision of local

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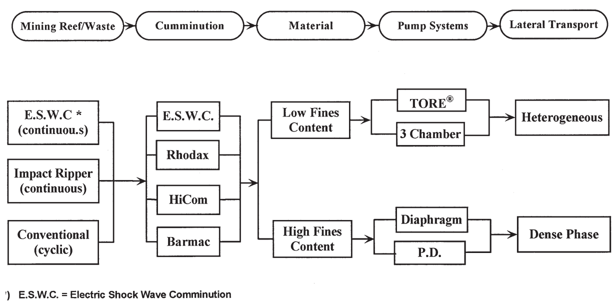


Figure 1—Concepts for underground comminution and hydraulic transportation

and regional support in deep level mining. A further use of the development waste will be for the replacement of reef stabilising pillars by cemented backfill (concrete), as mining depths increase. These backfills will need to be hydraulically transported in the 'dense phase flow regime' to ensure ultimate compressive strength.

Figure 1 shows a general schematic of CSIR Mining Technology's integrated research programme. The link between comminution technology and different pumping systems is shown. At present, various aspects of the elements shown are being evaluated with the aim of providing feasible configurations of technology and equipment to allow concentrated continuous mining with face advance rates considerably higher than those presently being achieved.

The process starts at the face where conventional mining methods will eventually be replaced by innovative non-explosive mining methods. The Impact Ripper technology, for instance, is currently under evaluation in different underground applications. Promising results have been obtained in stressed Carbon Leader reef at Doornfontein gold mine. Work on electric shock wave comminution (ESWC) technology is still limited to a laboratory and pilot plant scale. Negotiations are presently under way in Germany, USA and the UK for the commercialisation of the technology.

In concept, when the rock, either as reef or as waste for backfill, is broken, it will be removed from the face to a small comminution plant in close proximity to the stope. Depending on the comminution method selected, the particle size distribution envelope can be varied from a coarse aggregate with maximum particle sizes of up to 30 mm containing very little fines, to a material containing a large amount of fines, but with a limited top size of only 5 mm.

The objectives of the research programme are to establish which comminution methods and which hydraulic transportation systems are best suited for potential backfilling applications or for potential reef hydraulic transportation.

Some background information on continuous rock breaking

For many decades, mining engineers have been acutely aware of the limitations of batch mining methods based on the use of explosives. Because of the cyclic nature of mining, transportation systems for rock, men, and materials can lead to considerable congestion underground.

Mining is basically a transportation process and any delay in the transportation system can seriously affect the profitability of any mining operation. More than 500 000 tons of reef and waste are transported underground on an average working day, requiring in excess of 20 000 km of rail track alone. Further statistics over the past five years reveal that between 20% and 30% of the total mine accident hazards can be attributed to accidents related to mine logistics and transportation. Major contributors are in the areas of locos, mono-ropes, rails, scraper winches, falling material and manual handling.

A further area for consideration is the problem of fines generation, which often is accepted as an unavoidable consequence of any rock breaking or comminution process. Few would doubt that if ways could be found to break or comminute rock without the generation of excessive fines, major benefits to mining could be obtained.

The introduction of hydraulic transportation will constitute an integral part of future continuous mining operations and tremendous opportunities alleviating or eliminating many of the above-mentioned problems will be offered.

Results of electric shock wave comminution test work

The particle size distributions of three samples of South African reef, comminuted overseas using electric shock wave comminution (ESWC) technology, are shown in Figure 2. The reef samples were initially jaw crushed to a maximum particle size of about 75 mm prior to ESWC. The top sizes of the ESWC samples were dictated by the screen size in the ESWC chamber which was filled with water. ESWC was conducted in a single stage.

The graphs show that well-graded particle size distributions were produced from the reef samples in a single comminution process. The graphs also demonstrate the flexibility of ESWC to yielding distributions with any desired d_{50} in the particle size distribution.

Petrographic examinations indicated intergranular fracturing and disintegration along grain boundaries. Particle

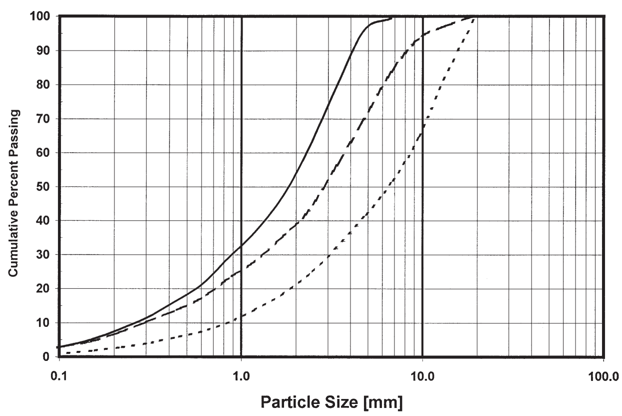


Figure 2—Particle size distributions of electric shock wave comminuted reef

morphology examinations provided evidence of rounded and cubic particle shapes rather than highly angular and sharp, as normally encountered in conventional impact crushing. The shape of the particles will be beneficial to hydraulic transportation and pipe wear in future pumping operations.

Underground comminution for backfilling

To reduce the extent of waste handling underground and, at the same time, provide a high performance backfill suitable for hanging wall support or the replacement of reef stabilising pillars in deep level mining, the development waste rock will require underground comminution.

In ultra-deep level mining, the backfill support characteristics need to be superior to conventional classified tailings backfill for instance. This can be achieved by reducing the backfill porosity, i.e. arranging particle size distribution so that the smaller particles fill the interstices created between the larger particles.

A sufficient amount of fines would be required, firstly, to hydraulically transport the larger particles in the dense phase flow regime, and secondly, to form a rigid matrix for strength development after placement. However, the hydraulic transportation of high fines containing dense phase slurries require high pump pressures. This would be particularly the case for high quality cemented backfills or 'concretes' for reef stabilising pillar replacement. Therefore, the use of positive displacement (PD) pumps or diaphragm pumps are necessary. Because of the higher pumping pressure requirements lateral distances for distribution of the backfills are limited to about 700 m.

To allow for temporary shut-downs of pipelines, the cementitious binder should preferably be added as close to the stopes as possible.

Figure 3 shows two typical particle size distributions of tailings/aggregate based backfills. The waste was conventionally comminuted underground using jaw and cone crusher technology. The aggregate was blended underground with classified tailings at two different blend ratios, as shown in Figure 3. This envelope represents a practical backfill range for hydraulically transportable backfills. Lateral transport over distances of up to 700m, using a single-stage pump station, have been easily achieved in practice to date.

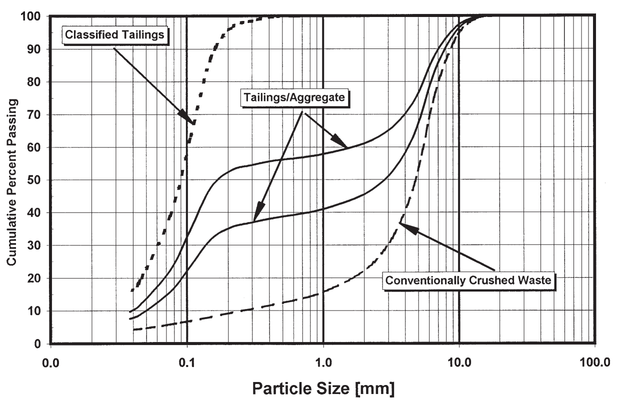


Figure 3—Particle size distributions of two high performance backfills

Full scale test work conducted by CSIR Mining Technology has confirmed that, due to the slow-settling characteristics of uncemented dense phase backfills in pipelines, it is possible to restart these pipelines even after shut-downs of several hours. This transportation feature will further enhance the integration of backfilling with continuous mining operations.

Test work conducted on development waste comminuted conventionally, has indicated that centrifugal pumps are not always ideally suited due to the rapid settlement behaviour of the product. Positive displacement pumps block immediately due to a lack of fines as a carrying medium.

As part of their research programme, CSIR Miningtek have identified a novel TORE® pump system that is able to introduce this type of material into pipelines for hydraulic transportation at solids concentrations up to about 60% by mass. Some of the results of test work using the TORE® pump are given later.

TORE® Pump System

A pilot plant of this hydraulic transportation device is installed and operated at CSIR's full-scale test facility at Western Deep Levels gold mine. The major components are a pressure vessel with a clear water inlet, a port for bulk solids feeding and a slurry discharge pipeline. The TORE® foot is located inside the vessel, close to the bottom.

Prior to pumping, the pressure vessel is filled with solids on a batch basis. CSIR Miningtek's research has indicated that best results in terms of filling and discharge operations are obtained when the solid particles are coarse and fast settling.

This property provides a high permeability of the settled material in the vessel and a distinct interface between slurry and clear water at the end of a batch discharge cycle. During the discharge of solids the TORE® foot provides a built-in solids pick mechanism and further solids settle to occupy the volume of the discharged solids during each pumping cycle.

Figure 4 shows a cut-away view of the general arrangement of the TORE® foot unit. The unit is fed with high-pressure water via a tangential inlet to a swirl chamber, generating a spinning motion. The water passes through a conical section which preserves the angular momentum. Once the water leaves the annulus, it mixes with the solids at the bottom of the vessel. The mixture of solids and water is discharged through the inner pipe as a slurry at a controlled solids concentration.

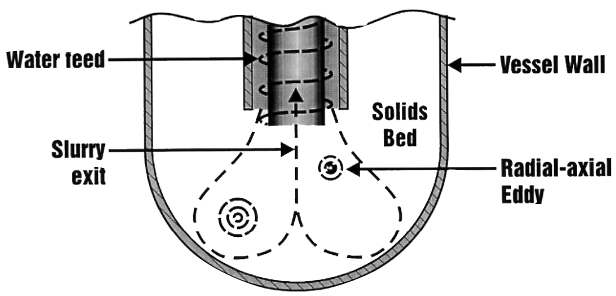


Figure 4—Cut-away section through a typical TORE® foot

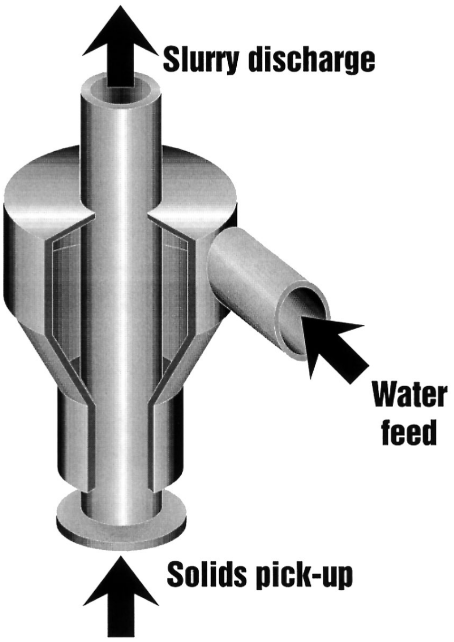


Figure 5—Typical flow patterns around the TORE® foot

Figure 5 shows the complex flow pattern developed around the TORE® foot. One parameter used to characterise the vortex flow is the swirl number, which is the ratio of axial flux of angular momentum to axial flux of axial momentum. Laboratory evaluations of the TORE® identified the formation of radial axial eddies at the cylindrical exit, and a precessing vortex core (PVC) which is typically associated with simultaneous forward and reversed axial rotating flows.

Coarse slurries successfully transported with TORE®

In the past, experience with coarse slurries indicated high wear rates of the centrifugal pump impeller and solids concentrations were limited to prevent blockages. However, promising results have been obtained using the TORE® pump system, which eliminates any contact of solids with moving parts, such as impellers or pistons. CSIR Miningtek have conducted TORE® pump evaluations on many materials with different particle size distributions using their pilot-scale facility.

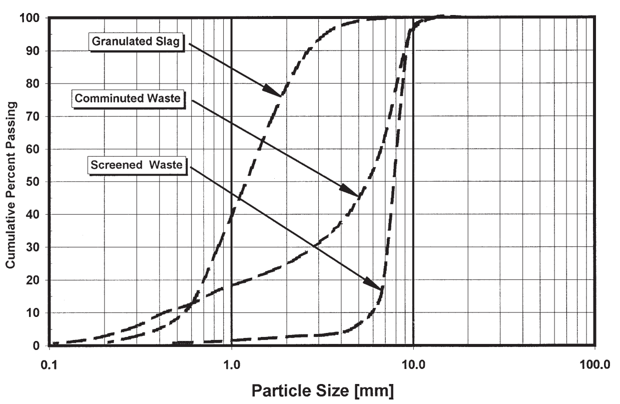


Figure 6—Particle size distributions of successfully pumped products

Figure 6 shows the particle size distributions of three of these. The d_{50} size ranged from about 1 mm to 8 mm and the particle size distributions ranged from uniform to well graded. These distributions were selected to identify the effect of varying particle size distributions on the pump performance.

- Granulated slag material, with a solid specific gravity (SG) of 3,0, was extensively used during initial evaluations of the TORE® under various operating conditions. The performance of the TORE® for pumping this material was extremely successful.
- A conventionally crushed waste material with a limited amount of fines and a maximum particle size of about 12 mm was also successfully pumped and hydrohoisted over a vertical distance of about 10 m. The top size of the slurry was limited to 12 mm due to the discharge piping diameter being 50 mm.
- Fine particles were screened out of the conventionally crushed development waste to provide an extremely fast-settling closely-sized material with a top size of 9 mm and only 10 per cent passing 6mm in the particle size distribution. The performance of the TORE® for pumping this material was successful again.

All bulk materials were fed via a conveyor into the TORE® vessel pre-filled with water, to ensure that no air remained in the vessel after filling. The solids settled quickly through the water and filling times were short. The solids displaced an equivalent volume of water during filling. This water was used in closed circuit to drive the next TORE® run. When the high pressure water was introduced into the vessel via the TORE® foot, an equivalent volume of slurry was discharged from the vessel. The solids concentration of the slurry depended on the complex 'fluidisation' pattern at the TORE® foot, as described above.

Slurry discharge concentrations

During each batch discharge, the system pressures, flow rates and slurry concentrations were monitored continuously with in-line flow meters and density gauges. Regular slurry samples were taken at short intervals at the discharge end of the pipeline. These samples were analysed in the laboratory for their particle size distribution and solids concentration.

The following table shows the obtained solids concentrations by mass of the three different materials.

The table shows that acceptable levels of solids concentrations between 45% and 67% by mass were achieved in practice.

It was possible to hydraulically transport the granulated slag at significantly higher solids concentrations than the crushed waste and screened waste materials, for two reasons: Firstly, the evenly graded particle size distribution of the granulated slag provided a range of particle sizes, which resulted in a low bulk porosity and hence equivalent high solids concentration. Secondly, the geometry of the TORE® foot was specifically optimised by CSIR Mining Technology, to obtain high solids concentrations, as required for a particular granulated slag hydraulic transportation application.

Table I

Maximum achieved slurry concentrations of various materials and their properties

Material type	Solids specific gravity	Top size [mm]	D_{50} [mm]	Maximum concentration by mass cm[%]
Crushed waste	2,7	12	6	48
Screened waste	2,7	10	8	45
Granulated slag	3,0	7	1	67

Effect of flow rate

A unique operating feature of the TORE® pump system is the 'fluidisation' of settling solids within the pressure vessel as pumping operations proceed. This 'fluidisation' is governed by the complex vortex and eddy flow conditions around the TORE® foot, as described earlier, and alters considerably with increasing volumetric flow rates.

Although the following section presents results which were obtained during a systematic test programme using granulated slag, the findings show the magnitude of possible operating envelopes of the TORE® system when using a bulk sample with a well graded particle size distribution.

Figure 7 shows the effect of different TORE® foot designs (A, B, and C) and achievable slurry concentrations for the same bulk slag material. The graph shows that, when using the foot nominated 'A', the solids concentration decreased significantly with increased volumetric flow rate. This indicated a less efficient 'fluidisation', in terms of the solids concentration obtained at higher flow rates. This was due to the occurrence of ineffective eddies around the foot. An increase in discharge slurry concentration, however, was achieved using foot 'B', which also provided a more stable slurry concentration in relation to flow rate. The features described above can be used to control and determine solids concentrations for selected applications. For example, when excess amounts of water need to be transferred or when available system pressures are limited, i.e. hydraulic transportation systems requiring low concentration transfer.

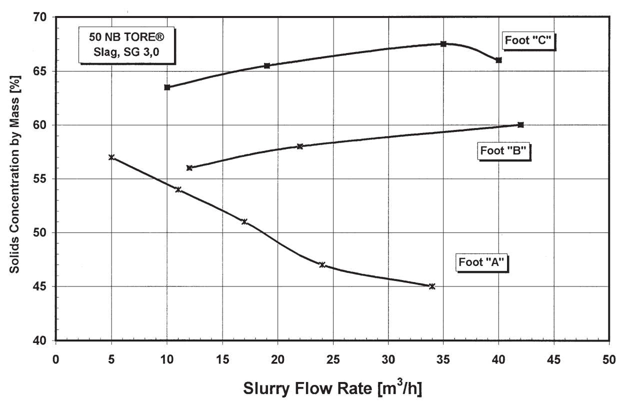


Figure 7—Effect of TORE® configuration on solids concentration

The highest possible slag slurry concentration of 67 % by mass was achieved with foot 'C'. The slurry flow behaviour was very stable and the discharge concentration remained high during the entire run. Further tests at this high solids concentration indicated that the transport velocity in the pipeline could be reduced significantly to about 1,5 m/s without pipeline blockages occurring. This would potentially reduce pipe wear considerably.

Comparison of electric shock wave comminuted samples with successfully pumped products

To date, no large bulk sample, produced by electric shock wave comminution (ESWC), has been available for hydraulic transportation test work. However, to assess the hydraulic transportability of the envisaged ESWC products, other products with similar particle size distributions to ESWC products were investigated for comparison.

Figure 8 shows an overlay of particle size distributions of ESWC products, as comminuted in the laboratory (Figure 2) and the particle size distribution of other products successfully pumped to date (Figure 6). The similarity of the shapes of the particle size distribution curves is encouraging and it is envisaged that the ESWC products will be very suitable for reliable hydraulic transportation. An additional benefit for trouble-free hydraulic transportation will be the cubic and more rounded particle shape of the ESWC products, as compared with the sharp, granulated slag material, or the flaky aggregate particles, as generated by conventional impact crushing.

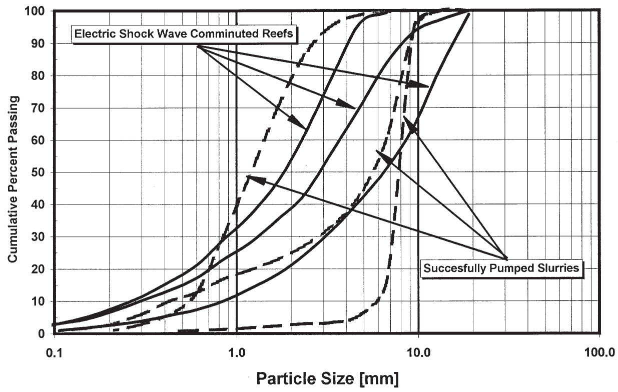


Figure 8—Particle size distributions of successfully pumped products and of reef comminuted by electric shock wave technology

Further work

Major efforts are being directed at establishing a pilot plant in South Africa for electric shock wave comminution of larger samples of reef and waste. This will enable not only the optimisation of the comminution requirements for hydraulic transportation, but also the production of large bulk samples of different reefs and wastes, from various South African mines on a regional basis.

Large bulk samples will enable further full-scale hydraulic transportation test work. A systematic test programme will then be conducted to establish the hydraulic transportation behaviour of the bulk samples in terms of transport velocities, pipe wear, critical slurry concentrations, pipeline pressure losses, and requirements to ensure restartability of temporarily shut down pipelines.

Conclusions

Through an integrated research programme, CSIR Mining Technology has identified suitable technologies and equipment for the underground comminution of reef and development waste to yield products with particle size distributions, suitable for hydraulic transportation. The use of underground rock comminution and hydraulic transportation may impact significantly on future concentrated and continuous mining.

Underground comminution of development waste by conventional means or by the novel methods discussed in the paper for potential use as high quality backfill will minimise waste transportation to surface and hence reduce congestion underground.

Electric shock wave comminution (ESWC) technology provides controlled particle size distributions with any desired top size. The ESWC process reduces the generation of fines and limits dust pollution underground.

An innovative TORE® pump system appears to be well suited for the hydraulic transportation of products produced by electric shock wave comminution. ◆

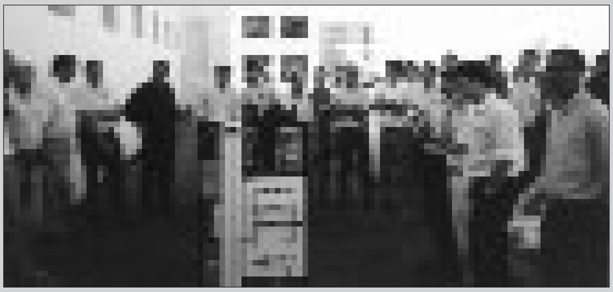
The design of slurry pipeline systems
A three-day course held in Cape Town on 12–14 March 1997*

Paterson & Cooke Consulting Engineers presented the second annual short course on the design of slurry pipeline systems in March. The course was held at the Breakwater Lodge in Cape Town's Victoria & Alfred Waterfront. Thirty-seven delegates from the Netherlands, Botswana and South Africa attended.

A main aim of the course was to convey to the delegates the importance of slurry flow behaviour when designing or selecting equipment for a slurry pipeline system. The first half of the course dealt with the analysis of different slurry types and flow regimes. Latest developments in mathematical models to predict the pipeline pressure gradients for heterogeneous, mixed-regime and non-Newtonian slurries were presented.

A fully instrumented 28 mm slurry pipeline test loop was used during the lectures to show various aspects of slurry flow. Visual observations of the flow phenomena gave the delegates an insight into the physical slurry behaviour. Many delegates found that the demonstrations clarified theoretical aspects. Data was recorded for sand, kaolin and kaolin-sand slurries at different solids concentrations.

The remaining sessions covered practical aspects of slurry transport systems. These included the selection of pumps making allowances for wear and performance derating, pipeline wear, suitable instrumentation and pump station layout and design. The course finished off with a general discussion and feedback session in which all the delegates freely participated. The responses from the delegates were all very positive and their constructive comments can only improve the content and layout of the course for next year.



Delegates enjoying the practical laboratory sessions at the Breakwater Lodge

The 1998 course is scheduled for 18 to 20 March 1998 and will again be held at the Graduate School of Business, University of Cape Town, Breakwater Lodge, Victoria & Alfred Waterfront, Cape Town.

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