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Tests on the beneficiation of coal fines*

by H.C. VOGES†

SYNOPSIS

An account is given of the tests being conducted by Iscor on the following processes for the beneficiation of coal fines: froth flotation, gravity separation, heavy-medium separation, and pneumatic and column flotation. The coals used in the tests came from the Durnacol, Tshikondeni, Grootegeluk, and Hlobane collieries. The problems involved in the dewatering of fine products are stressed.

From a theoretical study of the efficiencies that should be possible for a hypothetical South African coal, it is concluded that future fines-beneficiation plants in South Africa may use standard heavy-medium cyclones for coal down to 1 mm in size, fines heavy-medium separation for the 1 mm to 450 μm fraction, and column or pneumatic flotation for the minus 450 μm fines.

SAMEVATTING

Daar word verslag gedoen oor die toetse deur Yskor uitgevoer in verband met die volgende prosesse vir die veredeling van fynsteenkool: skuimflottasie, gravitasieskeiding, swaarmediumskeiding en pneumatiese en kolomflottasie. Die steenkool wat in die toetse gebruik is, is afkomstig van die steenkoolmyne Durnacol, Tshikondeni, Grootegeluk en Hlobane. Die probleme betrokke by die ontwatering van fynprodukte word benadruk.

Uit 'n teoretiese studie van die doeltreffendheid wat moontlik behoort te wees vir 'n hipotetiese Suid-Afrikaanse steenkool, word die gevolgtrekking gemaak dat toekomstige aanlegte vir die veredeling van fynsteenkool moontlik van standaardswaarmediumsiklone gebruik sal maak vir steenkool met 'n grootte tot so klein as 1 mm, swaarmediumskeiding vir fynsteenkool vir die fraksie van 1 mm tot 450 μm, en kolom- of pneumatiese flottasie vir die fynsteenkool kleiner as 450 μm.

Introduction

Until recently in South Africa, the fraction of run-of-mine (ROM) coal smaller than 0,5 mm was often dumped or added untreated to the washed product. The exception to this was in the production of coal for the metallurgical industry, which has long regarded fines as a valuable source of high-quality coal and has beneficiated fine coal by means of froth flotation.

This paper discusses tests to improve the recovery efficiency of froth flotation, as well as the use of several newly developed processes.

Top Particle Size

It is an undisputed fact that the liberation of a valuable mineral from an ore is facilitated by finer crushing. However, the unit cost of beneficiation, in terms of both capital outlay and operating expenses, increases with finer crushing. In most cases, the efficiency of recovery also decreases with smaller particle size. A further disadvantage with finer crushing is the increased moisture content of the product, resulting in increased transportation costs, or in a lower calorific value where the coal is consumed direct. Handling of the final product is also more difficult since chutes become blocked and the amount of belt-cleaning material increases. It is therefore necessary during plant design to evaluate these aspects in order to obtain the optimum top particle size. Two such studies have been undertaken by Iscor.

The first was a study done for Durnacol prior to the design of the No. 7 plant. Table I gives a comparison of theoretical and actual yields for two topsizes of Durnacol coal.

TABLE I
THEORETICAL AND ACTUAL YIELDS FOR DURNACOL COAL CRUSHED TO TWO TOPSIZES

Topsize mm	Process	Feed rate $t\,h^{-1}$	Theoretical yield $t\,h^{-1}$	Actual yield $t\,h^{-1}$
150	Heavy medium	92	37,1	36,0
	Froth flotation	8	6,7	4,0
	Totals	100	43,8	40,0
35	Heavy medium	87	35,4	34,3
	Froth flotation	13	10,4	6,2
	Totals	100	45,8	40,5

According to Table I, the theoretical yield increases with a finer topsize. The smaller increase in the expected yield should be noticed. This is because feed to the flotation plant increased with the smaller topsize, and because the known recovery efficiency of froth flotation was only 60 per cent, as against 97 per cent for heavy-medium separation.

The economies of the two topsizes in a plant with a feed rate of $100\,t\,h^{-1}$ are compared for capital costs in Table II, and for operating costs in Table III. The figures given are not actual values but were chosen to make a realistic comparison. It is shown that an extra yield of 2525 t per annum is possible with the smaller topsize but, with transportation costing R20 per ton, the cost of every

* Presented at the Colloquium on the Total Utilization of Coal Resources, which was held in Witbank by The South African Institute of Mining and Metallurgy in October/November 1989.

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TABLE II
CAPITAL COSTS FOR PLANTS BENEFICIATING COAL AT TWO TOPSIZES

Topsize mm	Size fraction mm × mm	Type of plant	Capital cost of feed		
			Rate $t\,h^{-1}$	Unit cost R per $t\,h^{-1}$	Total R
150	150 × 15	Heavy-medium drum	42	28 000	1 176 000
	15 × 0,8	Heavy-medium cyclone	50	54 000	2 700 000
	0,8 × 0	Froth flotation	8	72 000	2 576 000
	Totals		100		4 452 000
35	35 × 0,8	Heavy-medium cyclone	87	54 000	4 698 000
	0,8 × 0	Froth flotation	13	72 000	936 000
	Totals		100		5 634 000

extra dry ton would be about R266, which is considerably higher than the value of the coal.

The second study was done for Tshikondeni coal by Dr Gorzitzke. While the first study assumed that the efficiency of the flotation process did not change with the fines arising from further crushing, his work indicated that this assumption could be wrong.

Fig. 1 shows the increase in flotation feed with smaller ROM topsize.

The change in theoretically recoverable product from the fines arising from finer crushing is shown in Fig. 2. As can be seen, more intergrown coal is broken into flotation feed size, resulting in a lower theoretical recovery.

However, the adverse effect on the floatability of the coal was even stronger, as shown by Fig. 3. The flotation efficiency for the 'natural' fines originating from a 25 mm topsize crush was 91,5 per cent, while that for the fines originating from the 5 mm topsize crush was 72,9 per cent.

Fig. 4 shows how the total plant yield is affected by finer crushing. The theoretical yield keeps on improving with decreasing topsize, but the plant yield reaches a

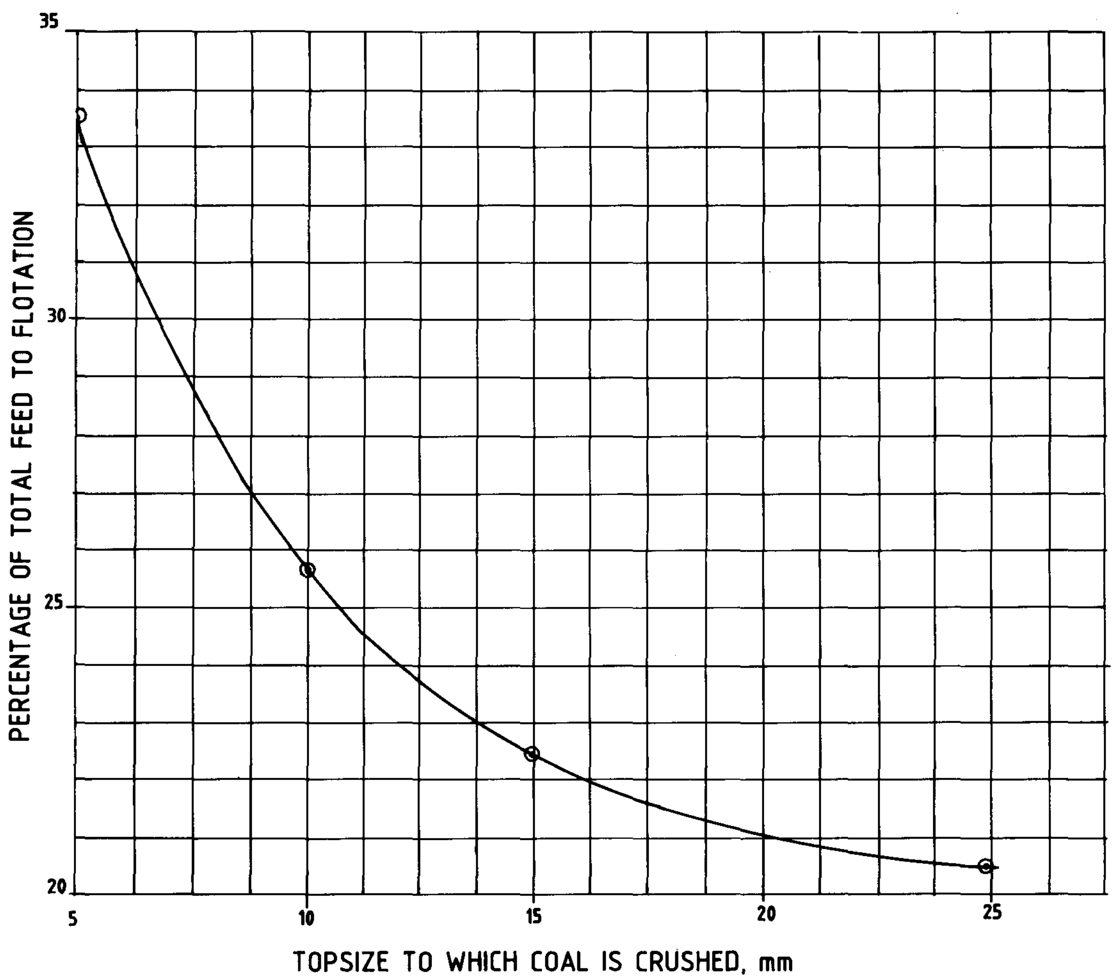

Fig. 1—Increase of flotation feed with finer crushing

TABLE III

OPERATING COSTS FOR PLANTS BENEFICIATING COAL AT TWO TOPSIZES

Topsize mm	Size fraction mm × mm	Type of plant	Operating cost		
			Feed rate $t\,h^{-1}$	Unit cost per ton R	Annual R
150	150 × 15	Heavy-medium drum	42	0,63	133 600
	15 × 0,8	Heavy-medium cyclone	50	1,70	429 300
	0,8 × 0	Froth flotation	8	2,39	96 500
	Totals		100		659 400
35	35 × 0,8	Heavy-medium cyclone	87	1,70	746 900
	0,8 × 0	Froth flotation	13	2,39	156 900
	Totals		100		903 800

maximum at a topsize of about 8 mm because of the drop in flotation efficiency.

Froth Flotation

South African coals are generally difficult to float. Tshikondeni coal floats well and Natal coking coals reasonably well, but most Transvaal coals are extremely difficult to float.

Efficiency as a Function of Product Ash Level

The efficiency of flotation recovery is reasonably good at high ash levels of the product, but decreases rapidly as products of lower ash levels are aimed for. Fig. 5 illustrates this in the case of Durnacol coal, where good efficiency can be obtained at 16 per cent ash but much lower efficiency is obtained at 12 per cent ash. With

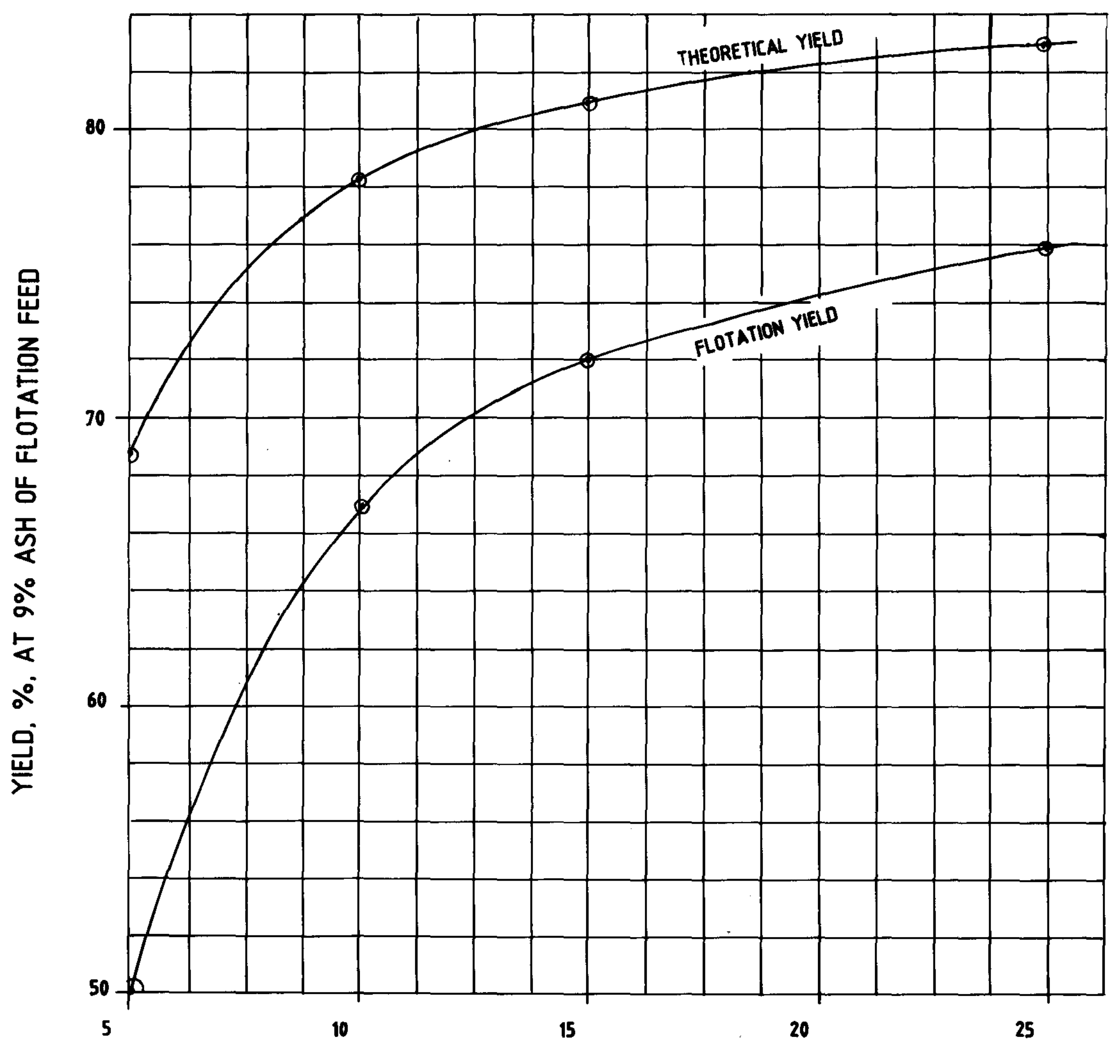

Fig. 2—Variation in percentage recoverable fines with finer crushing

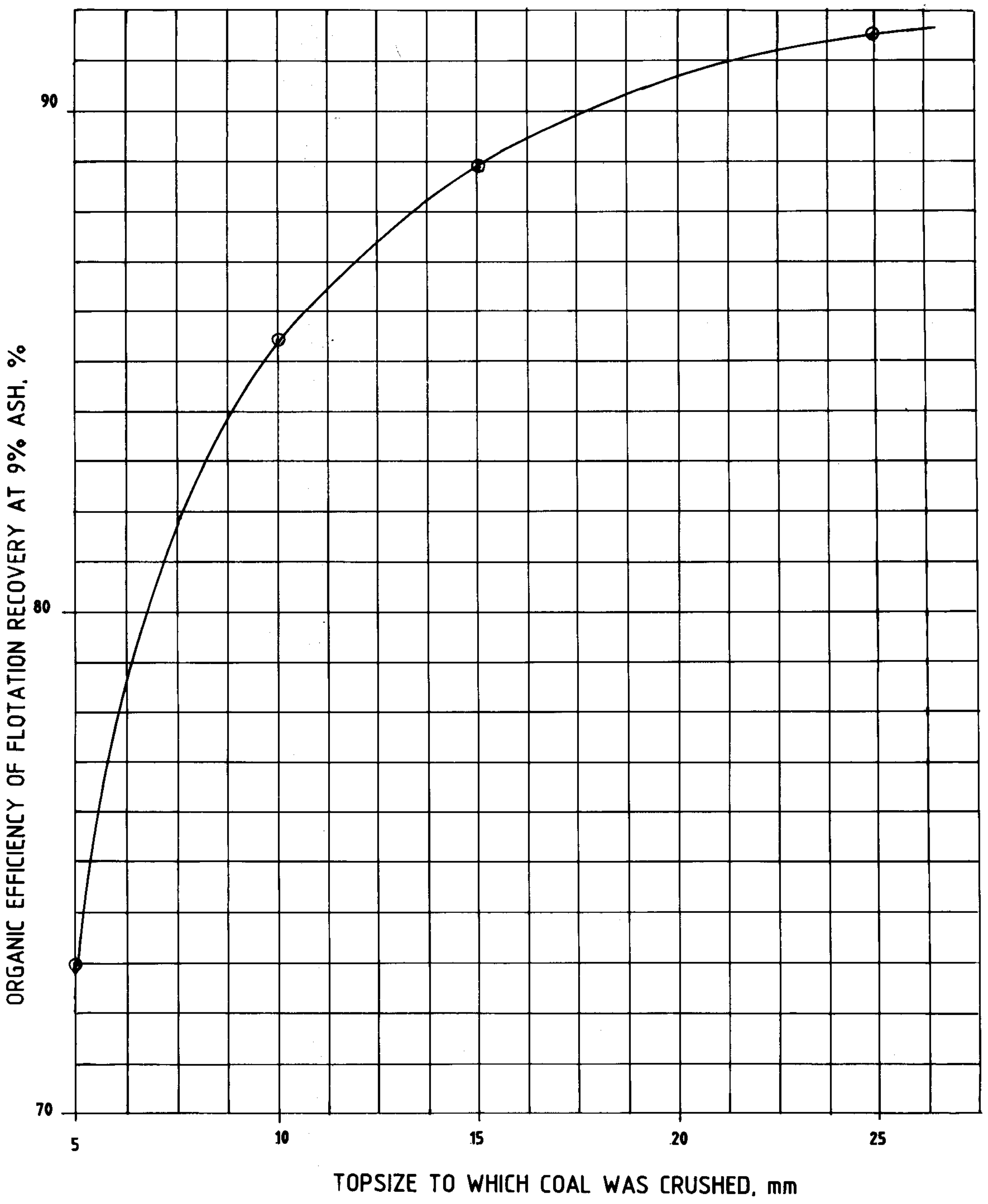

Fig. 3—Variation in flotation efficiency for fines originating from coal crushed to finer topsizes

Tshikondeni coal (Fig. 6), much better efficiency is obtained, but it also begins to drop with grades of concentrate better than 9 per cent ash.

It was found that it normally pays to run the flotation for a higher ash content in the concentrate than the plant contract value, and to overwash the concentrate in the heavy-medium plant to compensate for this.

Flotation Reagents

Iscor formerly used power paraffin as a collector and MIBC as a frother. Although it is difficult to improve the performance using this combination of reagents, some commercially available reagents tested were found to have the potential of replacing the standard reagents.

In an effort to reduce the consumption of power paraffin without loss of efficiency, specially developed additives (of unknown chemistry) are being tested. However, the results of the tests done so far are negative.

The use of coke-oven byproducts is also being investigated. The results on three coal mines indicate that these reagents give metallurgical results that are at least equal to those of power paraffin; the results were slightly inferior on a fourth mine. In some cases, however, the reagent consumptions were high. At Tshikondeni mine, this is now the standard reagent used.

Grootegeluk now uses a process in which the paraffin

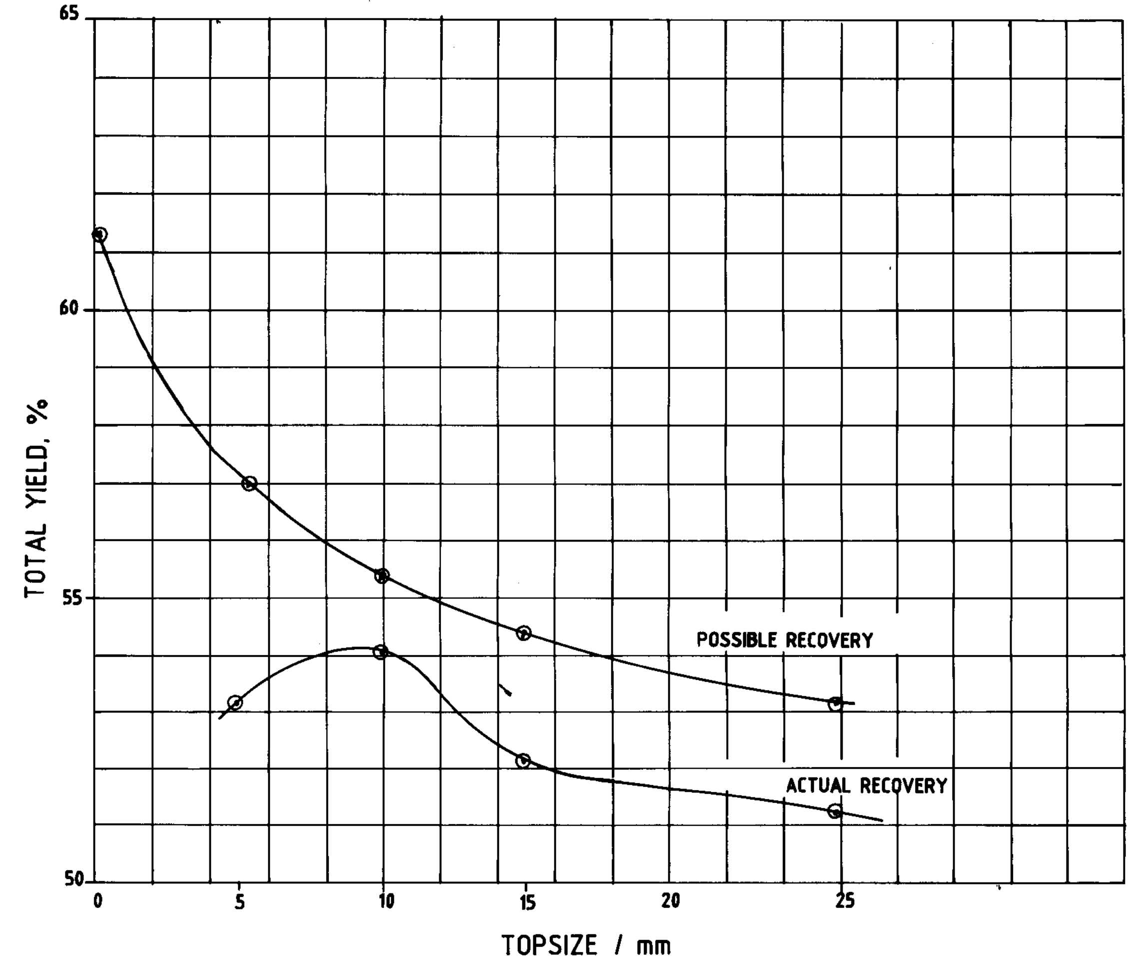

Fig. 4—Variation in total plant yield with change in topsize

is emulsified with water before being fed to the flotation circuit. This has resulted in a saving of 15 to 20 per cent in the amount of power paraffin required.

A meaningful improvement in flotation recovery was obtained by the addition of parts of the paraffin collector in the flotation cells. Two-thirds of the collector was added to the conditioner, and the remainder divided equally between the third and the fifth of six rougher flotation cells.

Desliming and Slimes Build-up

The flotation feed of Durnacol No. 7 plant is dewatered in two stages. The slurry is first fed to a Baum tower, the underflow of which is the major contributor to the flotation section. The overflow of the Baum tower is fed to a thickener, and the underflow of the thickener, only about 7 $t\,h^{-1}$, constitutes the rest of the flotation feed. The latter is, of course, much finer than the former.

It was soon observed that the flotation process stabilized about 30 minutes after start-up, but that the separation efficiency deteriorated seriously after about 4 hours of operation. Examination showed that a build-up of superfines was the cause of this deterioration. The build-up was caused by superfines returning to the flotation feed from the product filter. Since the filter problem could not be overcome immediately, it was decided to discontinue the addition of the thickener underflow to the flotation feed. Although this meant discarding a potential product of 3 $t\,h^{-1}$, the improvement in recovery from the rest of the feed compensated to such an extent that the product increased by about 8 $t\,h^{-1}$. The pneumatic flotation units mentioned later are now used to beneficiate the thickener product, and additional filter capacity has been provided.

The underflow of the Baum tower also contains superfines, and it was found that the total sulphur in the coal fed to flotation increased with the finer sizes, and this trend was repeated in the flotation product. Table IV illustrates these tendencies. These increases, together with the fact that a large portion of the flotation reagent is taken up by the superfines, suggest that desliming at, say 75 μm, could be advantageous.

Since such desliming by means of a screening device is unlikely to be practical, desliming by the use of cyclones was investigated. However, the difference in density between the low-ash and the high-ash superfine particles resulted in such increases of ash and sulphur in the cyclone underflow that desliming could not be recommended.

The importance of preventing the build-up of slimes between the flotation and the dewatering plants was again demonstrated in a recent test at Tshikondeni. Froth dewatering is normally done by means of a belt filter, with practically no return of superfines to the flotation

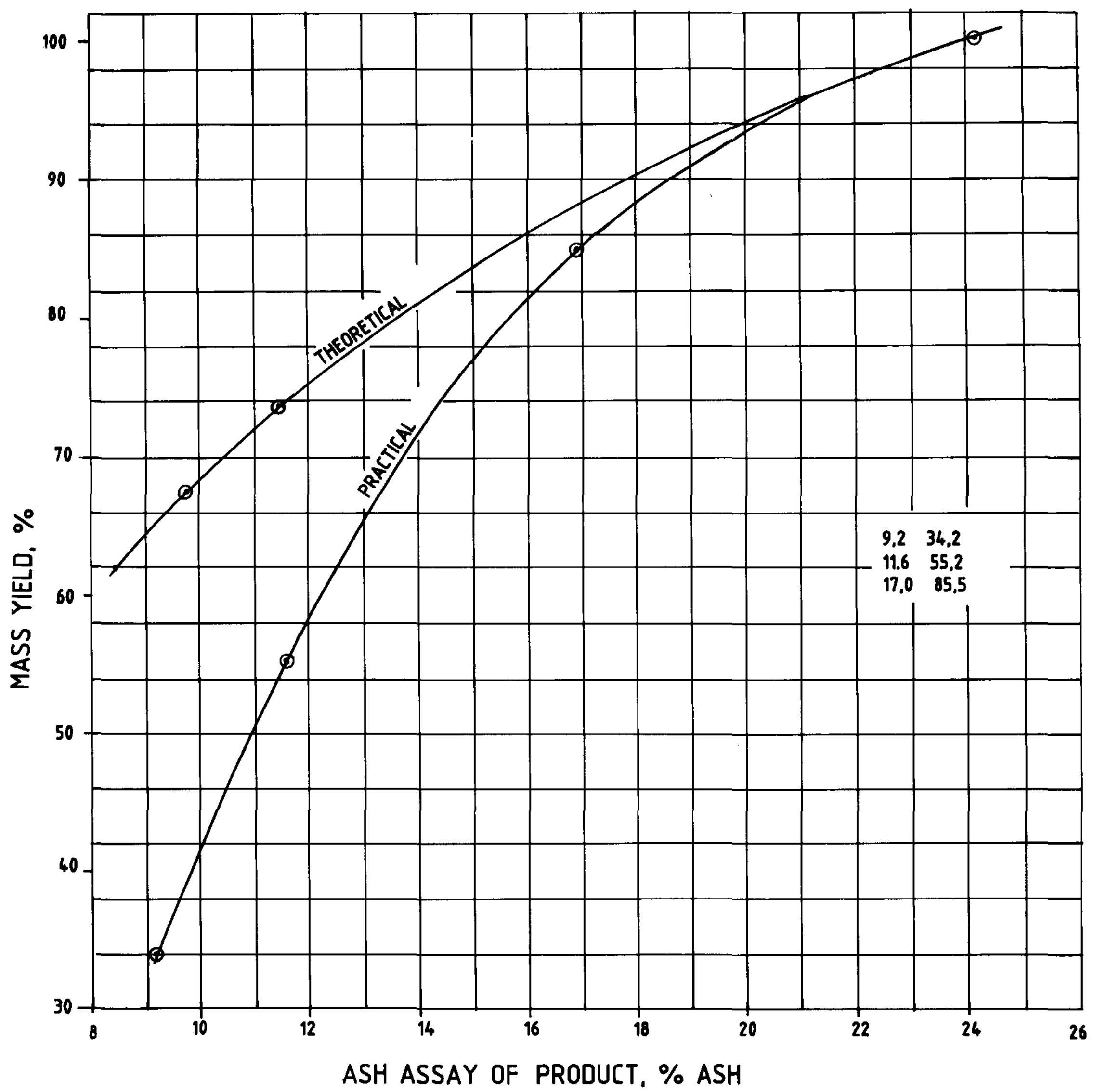

Fig. 5—Yields from Durnacol coal versus the ash assay of the product

TABLE IV
ASH AND SULPHUR ASSAYS OF THE FLOTATION FEED AND PRODUCT AT DURNACOL

Size fraction mm × mm	Flotation feed		Flotation product	
	Ash %	Sulphur %	Ash %	Sulphur %
1,00 × 0,84	29,1	1,65	6,0	1,47
0,84 × 0,50	27,1	1,64	7,2	1,54
0,50 × 0,21	25,0	1,64	10,2	1,58
0,21 × 0,15	27,0	1,68	15,3	1,69
0,15 × 0,074	38,2	1,59	18,9	2,06
0,074 × 0,044	58,7	1,29	19,1	2,25
0,044 × 0,000	59,6	1,90	15,0	1,64
Totals	31,1	1,64	12,2	1,68

section. Although much better dewatering was achieved with a centrifuge, the flotation efficiency deteriorated because of a build-up of slimes.

Amount of Collector Added

In a series of tests on Grootegeluk coal, increasing additions of collector resulted in an increased yield throughout, but the ash content of the product started at a high level (when only superfine shaly product was floated), then improved to a minimum value, and finally increased as high-ash intergrown particles started reporting to the product. The plant operator must therefore be sure of the section of the ash curve at which he is operating before making adjustments to the collector.

Retention Time

The flotation retention time required was in most cases about 3 to 4 minutes. At Grootegeluk, where provision was made in the flotation-cell capacities for a longer retention time, it was found that the recovery could be improved by shortening the retention times. A possible

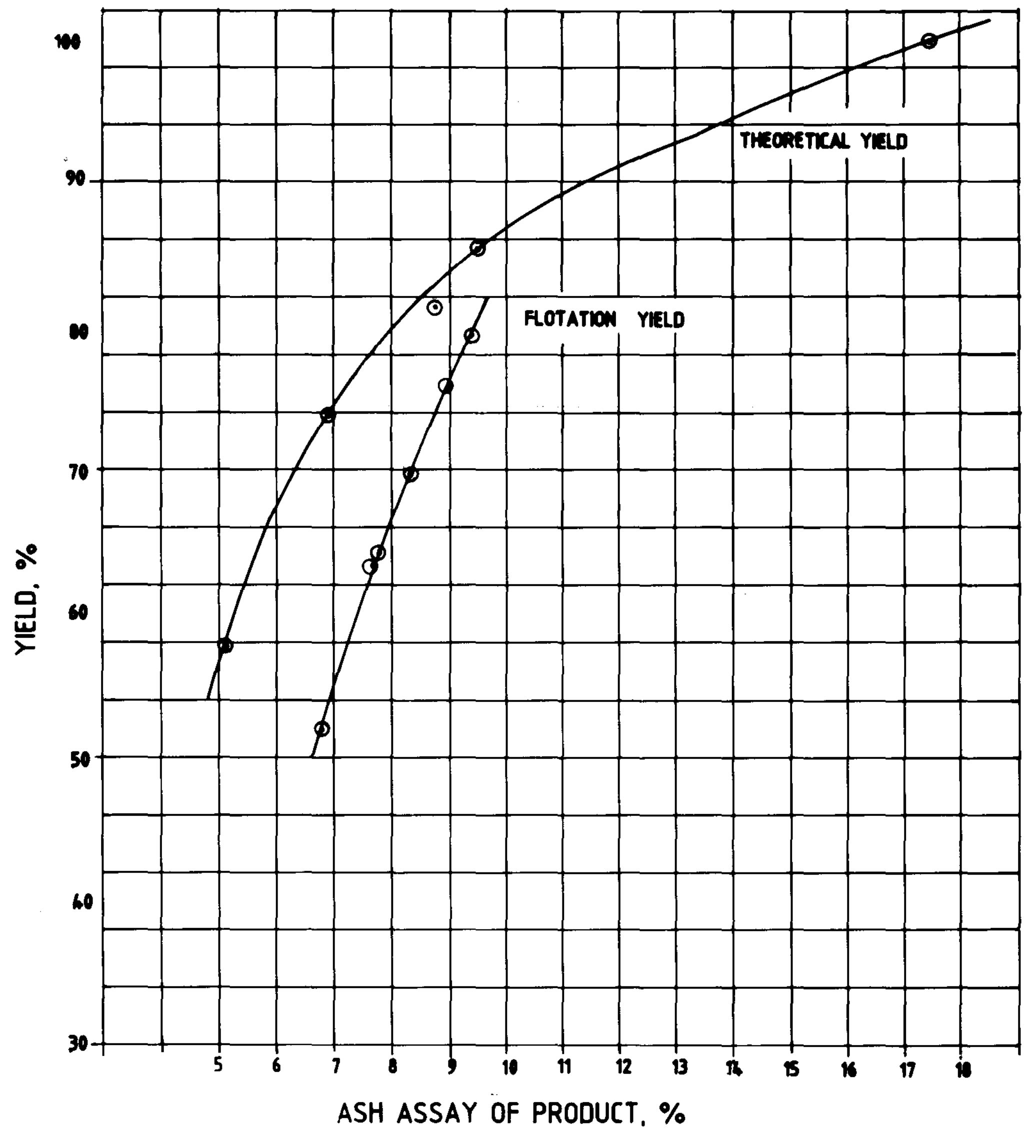

Fig. 6—Yields from Tshikondeni coal versus the ash assay of the product

reason for this is that the paraffin is absorbed into the coal particles, leaving their outside surfaces uncoated.

The removal of froth should also be efficient, since froth stagnating on the surface is apparently later lost in the tailing.

Suppression of Sulphur

Tests are being conducted at present to suppress the sulphur in froth flotation by surface oxidation with the help of bacteria.

Gravity Separation

The spiral has emerged during the past decade as a device that can beneficiate coal in the size range 100 to 1500 μm with fair efficiency. Good desliming of the feed or product is required, since practically all the minus 100 μm fines report to the product, and in most South African coals this fraction contains more ash than the other fines fractions.

The capacity of a spiral is only about 1,5 $t\,h^{-1}$ per spiral start, which means that the pulp stream has to be divided into several sub-streams. Much attention must be given to the design of the feed distributors to ensure equal distribution in terms of volume, percentage solids, and particle size. Larger spirals, with about three times the capacity of the conventional equipment, have been tested and found to be of equal efficiency.

The performance of a spiral is sensitive to the volume of feed, which should be kept as constant as possible. A considerable change in solids content and quality of the feed can be tolerated before a change in cutter setting is required.

Spirals can be used to supplement the flotation recovery of fines in different ways.

At Durnacol, where spirals are used to increase the yield and to lower the sulphur content, the total underflow from the Baum tower is first treated by spirals. The spiral product is then passed over a 300 μm sieve bend, the underflow of which is routed to the flotation plant. The plus 300 μm fraction is passed to final-product dewatering. Fig. 7 shows how, when only flotation was used, the plus 200 μm fraction of the flotation product

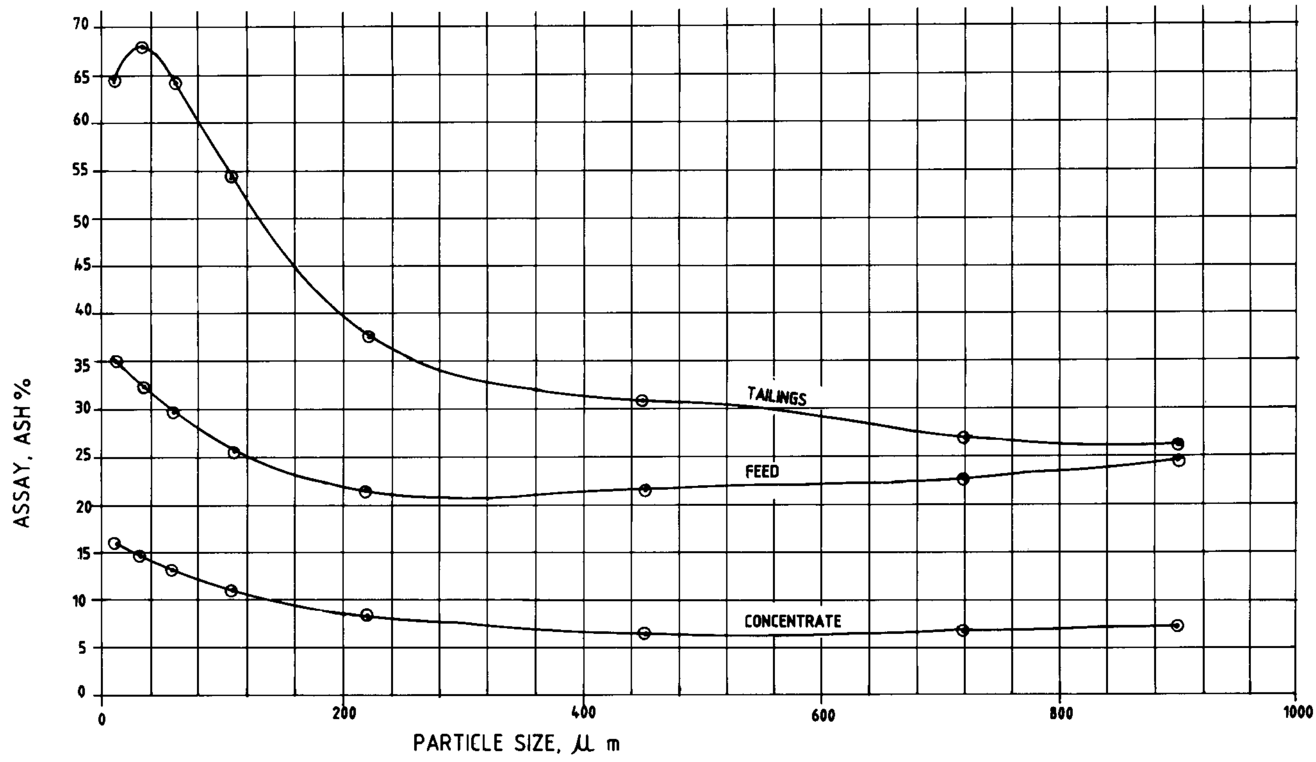

Fig. 7—Ash assay of feed, concentrate, and tailings at the Durnacol flotation plant

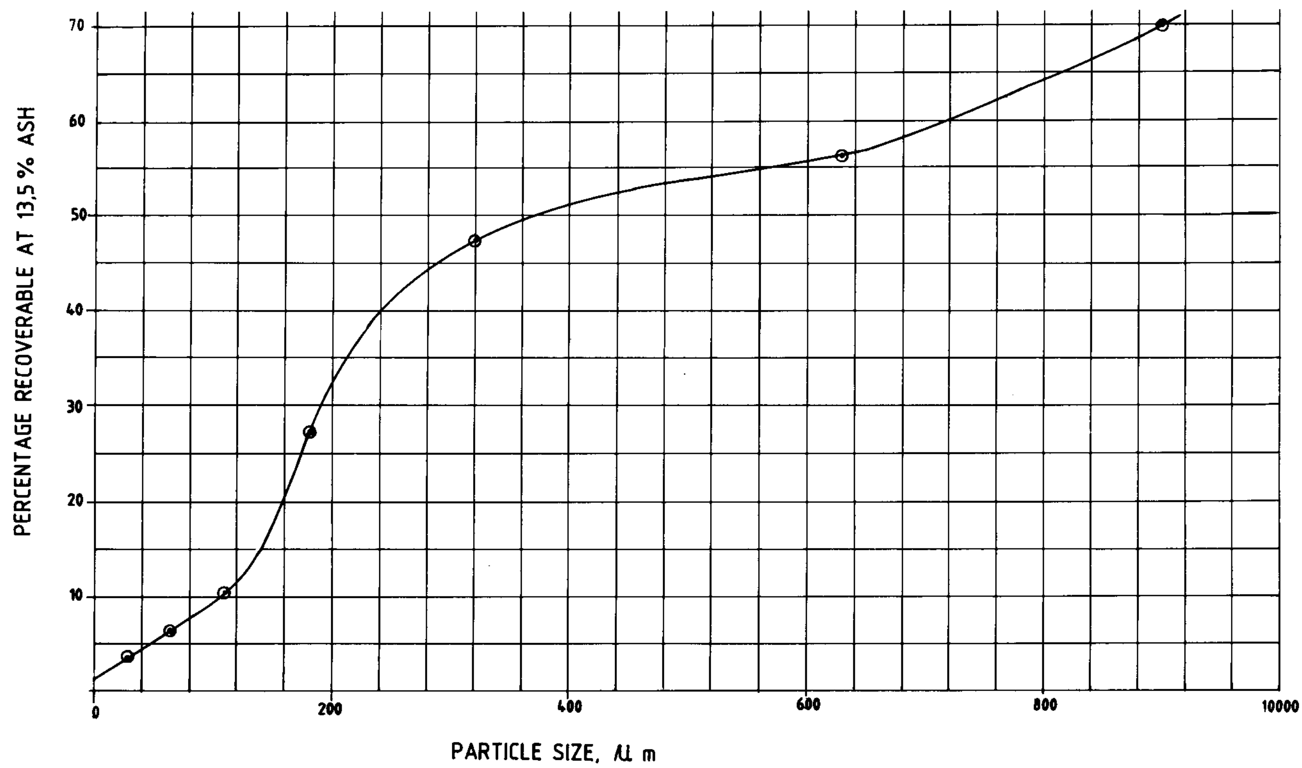

Fig. 8—Tailings recoverable at 13,5 per cent ash at the Hlobane flotation plant

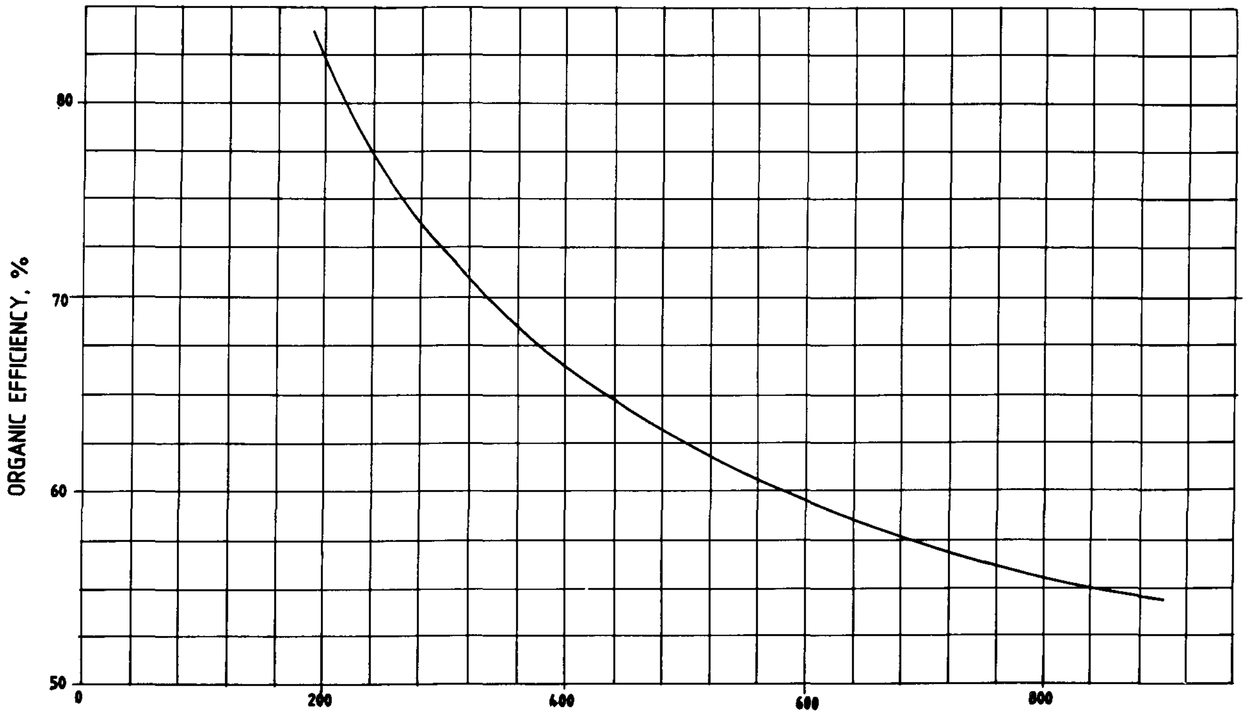

Fig. 9—Organic efficiencies achieved with flotation feed of different topsizes at Grootegeluk

TABLE V
COMPARISON OF FLOTATION RESULTS WITH COMBINED FLOTATION AND SPIRAL RESULTS

			Combination of flotation and spiral separation					
	Flotation only		Flotation		Spiral separation		Combination	
Product	Mass %	Ash assay %	Mass %	Ash assay %	Mass %	Ash assay %	Mass %	Ash assay %
Feed	100	35,3	50	36,4	50	34,6	100	35,5
Concentrate	23	15,0	9,5	12,0	18,3	13,4	27,8	12,9
Tailings	77	41,6	40,5	42,2	31,7	50,1	72,2	45,7

was over-beneficiated (i.e. coarse coal was lost to the tailing) while the ash content of the finer fraction was too high. This was rectified by the addition of the spiral section.

At Hlobane, where sulphur is no problem, the flotation tailing is classified in a cyclone and the underflow is re-treated in spirals. Fig. 8 shows the percentages of the flotation tailing in different size fractions that are recoverable at 13,5 per cent ash.

At Grootegeluk it is planned to classify the fines feed on 300 μm, and to treat the coarser fraction in spirals while the minus 300 μm fraction is still fed to the flotation plant. Fig. 9 shows how the efficiency of froth flotation changes with particle size. Table V gives the results obtained on the same sample of feed for the flotation-only route, and for a combination of flotation and spiral processes.

Shaking tables were also tested and gave similar results to spirals. Spirals are preferred because of their lower capital requirement. The water-only cyclone is another possible separator, and similar results are possible.

Other Separation Processes

Several other separation processes that are under test are briefly described below.

Heavy-medium Separation

Heavy-medium separation is potentially a very efficient process for the treatment of plus 100 μm fines. However, of three heavy-medium coal plants built in South Africa, only one is still in operation. The major problem appears to be the recovery of the medium. For efficient separation, the medium must be much finer than the product used in other cyclone plants. The superfine part of the magnetite medium is lost in the recovery circuit at a faster rate than the coarser part, resulting in too coarse a circulating medium for efficient separation. The recovery of such medium is an aspect that warrants much attention in future research.

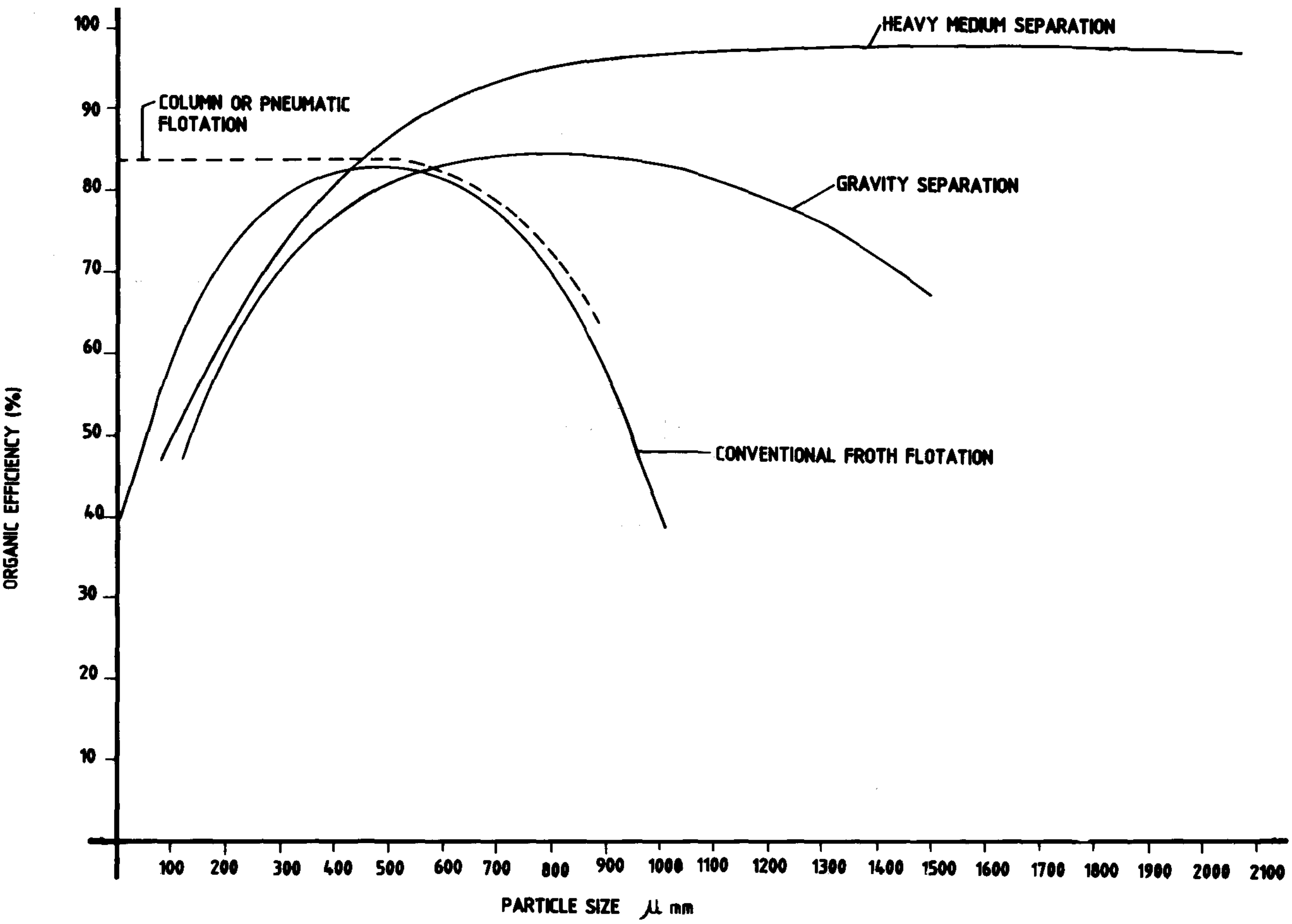

Fig. 10—Efficiencies that should be possible from different beneficiation processes on a hypothetical South African coal

Pneumatic Flotation

In a Bahr-cell test unit commissioned at the Iscor Pilot Plant during December 1987, testwork was conducted on the pneumatic flotation of minus 300 μm fractions of Grootegeluk and Durnacol fines, as well as on the total Tshikondeni flotation feed. The results obtained in a single stage were superior to those achieved with conventional two-stage flotation.

It is evident that a technique of great future potential has become available, and two commercial units have already been commissioned successfully at Durnacol mine.

Column Flotation

A test column-flotation unit was recently installed at Hlobane for the re-treatment of the cyclone overflow from the present flotation tailing. This overflow is dewatered in a thickener, and the thickener underflow was originally fed to the test column with poor results. The feeding of the thickener feed to the column, however, gave extremely good results. At the same time, a sample of thickener underflow was given to Professor King and Mr A. Juckes of the University of the Witwatersrand, and they obtained even better results.

The process will now be compared with pneumatic flotation in parallel tests at Hlobane.

Oil Agglomeration

Although not yet applied in South Africa, oil agglomeration is receiving considerable attention. One of the problems in the past was the high consumption of oil, but it appears that a breakthrough can be expected soon.

Dewatering

Dewatering is one of the aspects in fine-coal recovery that should be improved. Normal flotation concentrate is dewatered on a filter to a moisture content of about 20 per cent. The moisture content could be lowered on a centrifuge, but recirculating concentrate and persistent froth can lead to a build-up of fines in the flotation circuit, causing a drop in flotation efficiency.

One possible solution in the case of coking coal could be to add a fair quantity of coke-oven byproduct oil to the concentrate to expel water from the particle surfaces. This should lower the moisture, and the oil would be recovered at the coke ovens.

Conclusions

The design of a beneficiation plant always aims for maximum recovery but, unfortunately, this cannot be maximum recovery at any cost. In evaluating flowsheets, one must consider the cost per ton of the additional coal that will be recovered.

Cost considerations aside, Fig. 10 gives an estimate of the relative efficiencies that should be possible during the treatment of a hypothetical South African coal by the different processes discussed. The curves are not based on experimental results since such results for heavy-medium separation can be achieved only after the medium-recovery problem mentioned earlier has been solved, and more work will have to be done on column or pneumatic flotation.

If the assumptions made for Fig. 10 prove to be correct, the fines-beneficiation plants of the future could have standard heavy-medium cyclone separation for coal down to, say, 1 mm, fines heavy-medium separation for the 1 mm to 450 μm fraction, and column or pneumatic flotation for the minus 450 μm fraction. Based on present knowledge, spirals will have to be used for the 1 mm to 450 μm fraction.

If a breakthrough in fines dewatering cannot be made, it may not be worth while recovering the minus 75 μm fraction in most cases.

Acknowledgements

This paper is based on work done by P.H. Botha, W. Gorzitzke, M.I. Sidor, and others of the Iscor Pilot Plant; by P.E. Venter, W. Cornelissen, D. Krige, T. de Lange, and B. Coup of the Iscor Mining Department; and Prof. King and A. Juckes of the University of the Witwatersrand.

Record for mine-rope testing*

A record for testing mine ropes has been set up by the CSIR's mine-rope testing laboratory at Cottesloe, Johannesburg, for this year. The unit has also established a world record for the number of tests done over a five-year period. In August, 518 ropes were tested, compared with an average of 370 per month over the past 5 years.

Mine ropes are the thick steel cables used to raise and lower the skips, or cages, carrying men, equipment, and ore. By law, all mine drum-winder ropes in use throughout South Africa must be tested at Cottesloe every six months. This is done by pulling a section taken from each rope until it breaks, using a special testing machine.

'As far as we can ascertain, our unit has now tested the largest number of mine ropes in the world over the past five years', says Frieder Hecker, leader of the mine-rope testing unit of the CSIR's Division of Materials Science and Technology. 'We test a new rope before it is installed at a mine, and then retest samples from it every six months of its working life. From this, we can assess the safety of each rope.'

Over the past five years, ropes tested by the unit have raised well over 630 million tons of ore and transported more than 300 000 miners each day.

* Released by CSIR Public Relations, P.O. Box 395, Pretoria 0001.

From left to right: Messrs Hoosen Rehman, Rodgers Maluleke, and Solomon Khabo inspecting a rope after testing

Hydrometallurgy '91

Hydrometallurgy '91, the fourth in the series of international conferences organized by the Society of Chemical Industry, will be held from 2nd to 5th July, 1991, at Churchill College, Cambridge. The majority of the delegates will be accommodated within the College, offering opportunities for informal contact and social intercourse outside the main conference sessions.

As we enter the final decade of the twentieth century and as Europe approaches the single Market in 1992, the metallurgical industry, both within Europe and worldwide, has entered a period of recovery following the deep recession that afflicted it during most of the 1980s. During that period, technical developments in the industry virtually came to a standstill as companies struggled for survival, and many promising technologies were shelved or abandoned, except in the gold industry, where high gold prices led to a decade of unprecedented technical change and innovation in gold hydrometallurgy.

Following this period of stagnation, a renewed spirit of innovation and technical development is emerging within the metallurgical industry, and it is intended that Hydrometallurgy '91 will reflect this new environment. The engine driving these technological changes is the search for more-effective and cost-efficient methods of extracting metals from raw materials, which in general are decreasing in grade and increasing in complexity. In spite of increased demand in recent years, the longer-term outlook for many base metals is greater competition and threat of substitution by other materials such as plastics, composites, and ceramics. Hence, the need for continual efforts to lower the costs of metal production via improved technology.

Environmental issues have risen to the top of the political agenda in most industrialized countries. Pollution of air and water is now recognized as a problem of international, indeed global, dimension. Although the metallurgical industry has made vast improvements in pollution control over the past twenty years, much remains to be done, and the industry will find itself under unprecedented international political pressure in the coming decade to reduce the adverse environmental effects of its processing technologies.

With this scenario in mind, the Organizing Committee hopes to highlight the following areas of technological development at Hydrometallurgy '91:

Low Impact Extraction Techniques

In-situ leaching and solution mining; biohydrometallurgical processing.

Pollution Control and Waste Minimization

Safe disposal or recycling of hydrometallurgical waste products (e.g. Fe, As); treatment of effluent solutions; zero-discharge processing.

Rare and Precious Metals

Processing of refractory gold ore and gold refining; extraction and refining of platinum-group metals; processing of rare-earth metals.

Advanced Materials

Application of hydrometallurgical techniques for the production of ultrapure metals and advanced ceramics.

Enquiries should be directed to

The Conference Secretariat
Society of Chemical Industry
14/15 Belgrave Square
London SW1X 8PS
UK.

Tel: 01-235 3681. Fax: 01-823 1698.

Mineral Processing

The Universities of Cape Town and Stellenbosch, under the auspices of the Western Cape Branch of The South African Institute of Mining and Metallurgy, hold annual meetings to discuss research topics in mineral processing.

In 1989, this meeting took the form of an international colloquium on column flotation. The 1991 meeting will be the Tenth Annual Mineral Processing Colloquium.

For the tenth meeting, the Colloquium will be extended to 2 days, and speakers from other research groups and industry are invited to take part in this national meeting.

The object of this Colloquium is to

- discuss current research areas and findings
- keep abreast of recent developments in the industry
- elicit debate on relevant topics
- serve as a forum for informal contact.

Call for Papers/Posters

All interested persons are invited to participate in this event. Papers and posters will be presented. Only abstracts of the papers will be distributed and presenters are welcome to publish their findings elsewhere.

The dates for submissions are as follows:

30th April, 1991	Title and extended abstract (500 words)
31st May, 1991	Notice of acceptance of paper or poster.

Venue and Dates

The Colloquium will be held at the Van Riebeeck Hotel, Gordon's Bay, on 1st and 2nd August, 1991. Registration will take place on 31st July, 1991. A banquet will be held on 1st August, 1991.

To facilitate preliminary arrangements, anyone interested in submitting a paper or a poster, or attending the Colloquium should contact:

Mrs Meg Winter
Conference Secretary
c/o Department of Chemical Engineering
University of Cape Town
Private Bag
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Tel: (021) 650 2518. Fax: (021) 650 3775.