The beneficiation of fine coal by dense-medium cyclone

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SYNOPSIS

Various methods for the beneficiation of minus 0,5 mm coal are examined briefly, and tests are described on a cyclone of 150 mm diameter operating with magnetite as the medium.

It was found that, for sharp separations, at least 50 per cent of the magnetite should be finer than 10 μm. At that size, the ash content of the product was about 7 per cent at yields of 59 to 64 per cent, and the loss of medium was reasonable (about 1 kg per ton of fines treated).

SAMEVATTING

Verskillende metodes vir die veredeling van steenkool kleiner as 0,5 mm word kortliks ondersoek en toetse met 'n sikloon met 'n diameter van 150 mm wat met magnetiet as medium werk, word beskryf.

Daar is gevind dat vir duidelike skeidings minstens 50 per sent van die magnetiet fyner as 10 μm moet wees. Met daardie grootte was die asinhoud van die produk ongeveer 7 persent met opbrengste van 59 tot 64 persent, en die mediumverlies redelik (ongeveer 1 kg per ton fynkool behandel).

Introduction

The need to utilize energy resources judiciously is of global concern, and because coal is South Africa's main source of energy, the total utilization of coal (i.e., its mining, beneficiation, transportation, and usage) must be optimized.

Owing to the difficulty of cleaning minus 0,5 mm coal, the present practice is either to dump it or to add it to steam coal, despite the fact that these fines constitute a potential source of high-quality coal. Provided that the minus 0,5 mm coal can be upgraded economically to a coal of low ash content (about 7 per cent), it could be used as a blend coking coal.

Quality of Fine Coal

The results of washability tests on minus 0,5 mm coal indicate that an average yield of about 50 per cent and an ash content of 7 per cent can be obtained. Typical washability results for fines from Witbank No. 2 Seam are given in Table I. The minus 0,075 mm fraction amounted to 15 per cent of the minus 0,5 mm material and had an ash content of 25 per cent.

Table I indicates a theoretical yield of 58 per cent at an ash content of 7 per cent. If the organic efficiency is as low as 69 per cent, a practical yield of at least 40 per cent can be expected. It is conservatively estimated that about 3 million tons of this minus 0,5 mm coal are generated in South Africa annually. If these fines were prepared at the rather poor efficiency mentioned, 1,2 million tons of high-quality coal would be potentially available to industry per annum. Even at the low price of R15 per ton, this coal is worth R18 million per annum.

Difficulty of Cleaning

The washability results in Table I indicate that, at the relative density required to produce a product with an ash content of 7 per cent, the near-density material§ would amount to about 80 per cent. Coal from Witbank No. 2 Seam averages roughly 50 per cent near-density material, but this can range from about 20 per cent to as high as 80 per cent.

In 1928, Bird[1] related the degree of separating difficulty to the near-density content of coal, stating that, if this content exceeds 25 per cent, the separation becomes formidable. Clearly, this is indicative of the extent of the coal-preparation problem in South Africa.

During the 1976 Symposium on Coal Research in South Africa, Horsfall aptly described the beneficiation of fine coal in South Africa as follows: 'With fine coal drawn from seams having fairly easy washing characteristics, all available methods work; but with the more difficult coals, only dense medium processes will, in a single stage, give an efficiency of the order required'.

As far back as 1949, Van der Walt[2] indicated that reasonably sharp separations of minus 0,5 mm material could be effected in a dense-medium cyclone, and in 1977 Fourie and Erasmus[3] indicated that an écart probable value of 0,06 or better must be selected as the ideal in South Africa for units to be employed in the production of coal with an ash content of 7 per cent.

Other Beneficiation Methods

Froth flotation is probably the best-established method of cleaning minus 0,5 mm fines and is in extensive use abroad. In South Africa, however, froth flotation was confined until recently to the upgrading of coking-coal fines. Although these fines are classified, according to South African standards, as being amenable to froth flotation, the process is far from straightforward. Studies directed towards a search for more selective reagents included various frothers[4], like Aerofroth 65, Aerofroth 73, Aerofroth 77, pentanol, tri-ethoxy-butane (TEB), crude tar acids, and eucalyptus oil, in conjunction with paraffin as collector. Eucalyptus oil appeared a very promising reagent, even when used on its own. It was

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§Material with relative densities lying between the limit 0,1 on either side of the cutpoint.

TABLE I

WASHABILITY OF COAL FROM WITBANK NO. 2 SEAM, SIZE FRACTION BETWEEN 0,5 AND 0,075 mm

Relative density	Fractional		Cum. floats		Cum. sinks	
	Yield %	Ash %	Yield %	Ash %	Yield %	Ash %
F1,30	9,5	2,6	9,5	2,6	90,5	17,9
1,30–1,34	8,0	4,2	17,5	3,3	82,5	18,2
1,34–1,38	9,5	6,0	27,0	4,3	73,0	20,9
1,38–1,42	13,0	7,6	40,0	5,4	60,0	23,8
1,42–1,46	12,2	9,8	52,2	6,4	47,8	27,4
1,46–1,50	11,3	12,7	63,5	7,5	36,5	32,0
1,50–1,54	8,4	14,6	71,9	8,3	28,1	37,2
1,54–1,58	5,6	20,4	77,5	9,2	22,5	41,4
1,58–1,62	3,9	22,5	81,4	9,9	18,6	45,3
1,62–1,66	3,4	27,1	84,8	10,5	15,2	49,4
1,66–1,70	3,2	35,6	88,0	11,5	12,0	53,1
S1,70	12,0	53,1	—	—	—	—
Whole coal	100,0	—	100,0	16,5	—	—

also found effective for certain weakly coking coals[5, 6].

Other collectors[5,6], such as kerosene, dieselene, and turpentine, were investigated, but the outcome was not entirely satisfactory. It is possible that more careful studies would reveal more effective reagents, and this is being pursued.

In contrast, the flotation of non-coking coals proved disappointing in the extreme. Their poor floatability is attributed to the small amount of 'bright' coal they contain.

As a means of cleaning fine coal, water-only cyclones appear attractive for two reasons: they offer likely capital-cost advantages, and they can easily be integrated in existing dense-medium washing plants. However, it has been found[7,8] that the accuracy of separation is not as a rule sufficiently high to enable this type of separator to rank as an alternative to any of the established dense-medium processes for small coal. A degree of cleaning is undoubtedly achieved, but the écart probable is about 0,25.

Tests have indicated that the water-only cyclone operates both as a density separator and as a classifier. This results in the cutpoints of various size fractions of the feed being distributed over a wide range of relative densities, and the overall cutpoint is noticeably higher if a considerable amount of fine material is present. The separating effect in the minus 150 μm fraction is almost negligible, and that on the coarser fractions is merely an ash reduction; for example, the ash content can be reduced from 17,6 to 15,4 percent at a yield of 75,2 per cent, while the theoretical yield according to the washability characteristics is as high as 94,0 per cent at the same ash content.

Tests on the compound water cyclone[9] or tricone produced promising results. For example, a raw coal smaller than 0,5 mm with an ash content of 18,2 per cent was washed to give a product with an ash content of 12,8 per cent. The ash content of the plus 150 μm size fraction was found to be 9,4 per cent, and that of the minus 150 μm fraction was still as high as 16,7 per cent. Appropriate desliming can be applied, but that leaves the fraction between 150 and 75μm almost untreated. It is therefore considered unlikely that the hydrocyclone will find wide application in the beneficiation of minus 0,5 mm coal.

Concentrating tables are widely used in the U.S.A. but they are not yet in commercial use in South Africa. Research[10], however, has indicated that the low capacity of these units can be a major drawback: a quarter-size table cannot handle much more than 0,5 t/h if coal of 7 per cent ash is to be produced from coal smaller than 1 mm. Écart probable values were about 0,08 with serious 'tails' increasing the ash content, and the organic efficiencies were as low as 72 per cent.

Various combinations of flotation, water-only cyclones, and tables were investigated[5,6], but a product of about 7 per cent ash could be obtained only when the table was used as the second-stage unit. However, this configuration has the disadvantage of low capacity.

Work Done Elsewhere

In the U.S.A., Deurbrouch[11] has shown the suitability of the dense-medium cyclone for washing down to 0,075 mm. Sokaski and Geer [12] have made similar reports, and Mengelers and his co-workers[13, 14] have produced several papers on this subject.

In 1957, the Dutch State Mines and Coppee designed and built two dense-medium cyclone plants in Belgium, at Tetre and Witerslag, which treated a feed smaller than 10 mm with effective cleaning to about 0,15 mm. Similar plants followed in the U.S.A., but, although encouraging, the separations were still not of the required efficiency and sharpness[15].

Unfortunately, most South African coals have difficult washability characteristics. Recourse had therefore to be made to the dense-medium process for the cleaning of minus 0,5 mm coal, but the process had first to be refined to suit the circumstances.

Pilot Plant

With this objective, the Fuel Research Institute in 1976 erected a dense-medium cyclone pilot plant for the beneficiation of minus 0,5 mm coal, and commissioned it during the first quarter of 1977. Fig. 1 is a simplified

TABLE II

SCREEN ANALYSIS OF THE MAGNETITE USED INITIALLY

Size μm	Oversize %
250	0,9
90	1,8
50	5,5
32	33,8
20	90,4

TABLE III

EARLY PLANT PERFORMANCE

Test	Near-density material %	Cut-point	Organic efficiency %	Écart probable 75/25
1	51	1,46	89,3	0,035
2	25	1,57	85,3	0,063
3	49	1,44	80,1	0,073

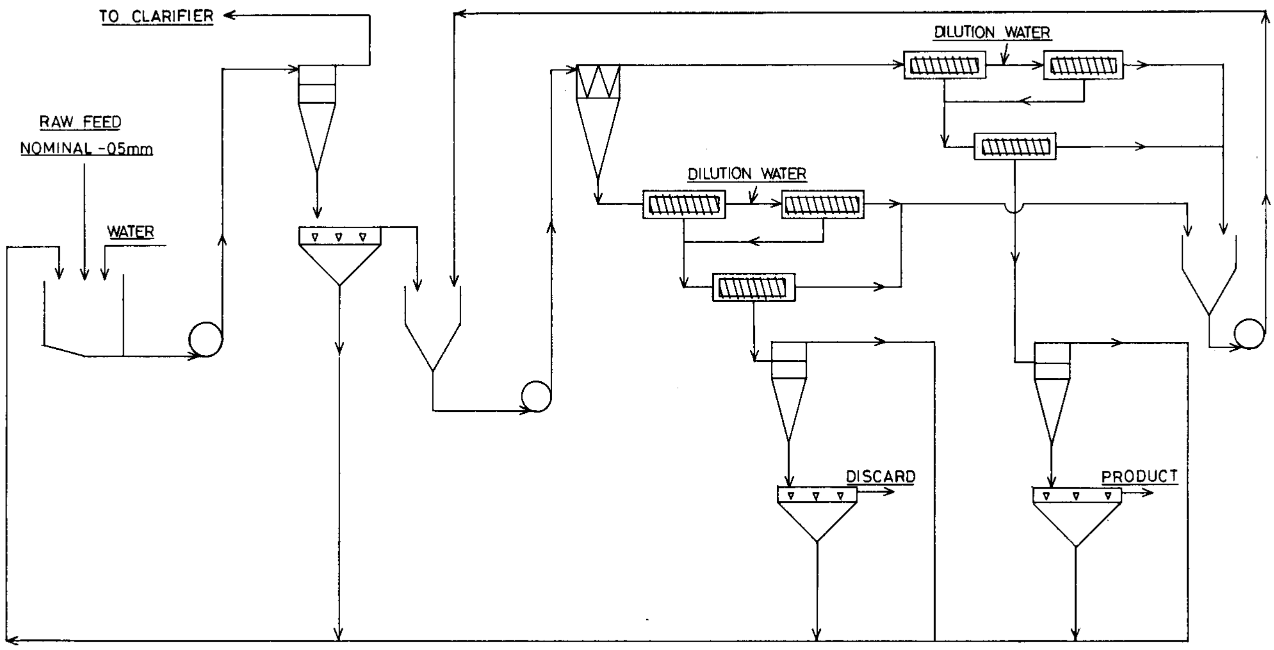

Fig. I—A simplified flowsheet of the dense-medium cyclone plant

diagram showing the flow of the solids and the medium in the pilot plant.

Raw coal nominally smaller than 0,5 mm is deslimed in a cyclone and dewatered on a screen. The fraction between 0,5 and 0,075 mm is mixed with correct dense medium, and is pumped to a separating cyclone 150 mm in diameter. Magnetite is recovered from the washed coal by a bank of magnetic separators, the cleaned coal being thickened in a cyclone and finally dewatered on a screen. The discard from the separating cyclone is treated in a similar way. Each bank of magnetic separators comprises a rougher unit feeding to a cleaner unit, the underflow from both reporting to a scavenger unit.

The following are some of the characteristics of the separating cyclone:

Coal feedrate	5 t/h
Pulp feedrate	35 000 l/h
Operating pressure range	85 to 150 kPa
Diameter	150 mm

Pilot-plant Test

Fairly coarse magnetite was used in the beginning as shown in Table II.

Although the separations were promising (Table III), fairly high losses of magnetite (about 2 to 3 kg per ton of feed coal) were recorded. These losses relate to magnetite that adhered to the products, and exclude any losses in the effluent, which were not measured.

In an attempt to improve the separating performance, much finer magnetite was employed, the size grading shown in Table IV being typical. The plant efficiency improved dramatically, but, as the very fine magnetite was gradually lost from the circuit, the separations deteriorated. The results of Table V are typical of that stage of the investigation.

In Tests 2 and 3, the very fine magnetite was still present, whereas in Test 1 it had been lost from the circuit, indicating that the fineness of the medium is of prime importance for efficient separations.

A batch of extra-fine magnetite with only 2 per cent oversize material at 27 μm was obtained and used, resulting in very sharp separations. However, the magnetite losses were beyond control, and it was decided that this aspect should be investigated further. A method of freeing the clean coal and discard from the adhering magnetite and of recovering the very fine magnetite from the effluents by a Magnadisc system proved to be an effective solution to the problem.

The stage had now been reached where sharp and efficient separations could be obtained at a wide range of relative densities (1,40 to 1,90) and at an acceptable loss of medium. However, all the tests had been con-

TABLE IV

SCREEN ANALYSIS OF FINER MAGNETITE

Size μm	Oversize %
45,0	3,5
27,1	12,5
20,8	20,0
14,8	33,5
10,0	42,7
7,4	49,5

ducted over short test periods (about an hour's duration), and continuous runs of, say, eight-hour shifts for several days were considered essential to prove the suitability of the process for commercial operation.

It was also decided that more efficiency parameters should be included in the studies. The drawback of the écart probable concept is that it takes no cognizance of the asymmetry of the partition curve, and the 'tails' are also frequently ignored. For a better understanding of the performance of the unit, it was decided that the following parameters should be evaluated in all future tests:

(a) partition density and equal errors cutpoint,
(b) écart probable values at partition coefficients of 25/75, 90/10, and 95/5,
(c) organic efficiency,
(d) misplaced material in the product and in the discard.

It was further decided that, before a continuous run was attempted, a systematic study should be made of the optimum magnetite fineness for the process.

As a first step, ready-ground very fine magnetite commonly supplied to the market was used as a medium. With this magnetite the difference between the overflow and the underflow densities of the separating cyclone were found to be about 0,9. Under these circumstances, poor performances were recorded.

By the use of progressively finer magnetite, the performance improved, and after considerable testwork it was decided that the size gradings shown in Table VI are ideal.

A bulk sample of minus 0,5 mm fines from Witbank No. 2 Seam weighing several hundred tons was obtained, and the plant went into continuous operation for some seventy hours. The results of four tests carried out during this period are given in Table VII, showing that excellent performance was obtained at a low consumption of medium.

Conclusion

It can be concluded that the ready-ground magnetite as supplied to industry at present is not fine enough for the beneficiation of minus 0,5 mm coal by dense-medium

TABLE V

LATER PLANT PERFORMANCE

Test	Near-density content %	Cut-point	Organic efficiency %	Écart probable	Magnetite losses kg/t	Misplaced material In product	Misplaced material In disc
1	45	1,47	—	0,089	0,7	8,6	14,7
2	44	1,45	83,7	0,029	1,9	7,2	6,0
3	51	1,41	76,9	0,038	2,7	8,7	6,8

TABLE VI

IDEAL SIZE DISTRIBUTION OF MAGNETITE

Size µm	Maximum oversize %
45	1
10	50
7,4	55

TABLE VII

PLANT PERFORMANCE DURING PERIOD OF CONTINUOUS OPERATION

Parameter	6,5% ash 53,1% yield	7,7% ash 64,2% yield	7,4% ash 58,8% yield	5,9% ash 43,3% yield
Partition density	1,46	1,50	1,48	1,432
Equal errors cutpoint	1,46	1,50	1,48	1,436
Écart probable 75/25	0,022	0,031	0,025	0,020
90/10	0,054	0,065	0,068	0,051
95/5	0,085	0,087	0,118	0,078
Organic efficiency, %	91,6	93,0	93,2	93,1
Misplaced material in product, %	5,1	5,2	4,8	4,7
Misplaced material in discard, %	3,6	6,2	4,6	3,8
Total misplaced material, %	8,7	10,4	9,4	8,5
Magnetite losses in effluent, g/l	0,03	0,02	0,045	0,05
kg/t feed	0,16	0,11	0,45	0,35
Magnetite losses adhering, kg/t feed	0,65	1,00	0,87	0,55
Total magnetite losses, kg/t feed	0,81	1,11	1,32	0,90

cyclone. For sharp separations, at least 50 per cent of the magnetite should be finer than 10 µm. However, if the magnetite is milled too fine, the losses may become excessive.

With magnetite milled to the required specification, the losses are reasonable, at an average of about 1 kg per ton of coal treated. An average of 0,7kg per ton of coal treated for adhering magnetite is probably as low as one can expect. The loss in the plant effluent, which averaged less than 0,3 kg per ton of coal treated, appear exceptionally good if it is remembered that it consists of magnetite substantially below 7,5 µm in size.

In view of the excellent separations and low losses of medium achieved over the continuous test run, it was concluded that the process was ready for commercial installation. The first plant using this process is currently under construction at Greenside Colliery. It is being built as an integrated extension to the existing plant on No. 2 Seam. Provision is being made to produce both low-ash coal and middling from a feed that is nominally between 0,5 and 0,075 mm at a maximum feed rate of 45 t/h.

Acknowledgement

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References

1. Bird, B. M. Interpretation of float-and-sink data. *Proceedings Second International Conference on Bituminous Coal*, vol. 2. 1928.
2. Van der Walt, P. J. Operating characteristics of the cyclone washer (2nd progress report of research in conjunction with the D S M cyclone washer). Pretoria, Fuel Research Institute, *Report* no. 17. 1949.
3. Fourie, P. J. F., and Erasmus, T. C. Beneficiation of fine coal in the Republic of South Africa. Pretoria, Fuel Research Institute, *Report* no. 58. 1977.
4. De Ridder, G. J. 'n Verslag oor die toepassing van die skuimflottasieproses in die steenkoolvoorbereidings laboratorium. Pretoria, Fuel Research Institute, *Tech. Memo* no. 4. 1972.

5. Fourie, P. J. F. Report on the beneficiation of $-0,5$ mm fines from Doornfontein Colliery. Pretoria, Fuel Research Institute, *Tech. Memo* no. 31. 1974.
6. Hanneman, H. A., Saler, A., Kuhn, A. H., Fourie, P. J. F. Report on the beneficiation of Landau 3 minus 0,5 mm fines. Pretoria, Fuel Research Institute, *Tech. Memo* no. 4. 1974.
7. Gardiner, W. Report on work done on the hydrocyclone plant at the Fuel Research Institute. Pretoria, Fuel Research Institute, *Tech. Memo*, no. 54. 1969.
8. Saler, A., and Streicher, S. F. Some remarks on the hydrocyclone unit of the Fuel Research Institute and its comparison with the compound water cyclone. Pretoria, Fuel Research Institute, *Tech. Memo*. no. 28. 1971.
9. Saler, A. Report on a compound water cyclone investigation on Van Dyks Drift fines. Pretoria, Fuel Research Institute, *Tech. Memo*. no. 15. 1973.
10. Kuhn, A. H. Report on beneficiation of Van Wyks Drift minus 0,5 mm fines with the Deister table. Pretoria, Fuel Research Institute, *Tech. Memo*, no. 9. 1974.
11. Deurbrouch, A. Washing fine size coal in dense medium cyclones. Washington, U.S. Bureau of Mines, *RI* 7982. 1974.
12. Sokaski, M., and Geer, M. R. Cleaning of unsized fine coal in a dense medium cyclone pilot plant. Washington, U.S. Bureau of Mines, *R.I.* 6274.
13. Mengelers, J., and Absil, J. Cleaning coal to zero in heavy medium cyclones. *Mining and Processing*, May 1976.
14. Mengelers, J. The H M Cyclone for fine coal beneficiation. C P S Conference, Johannesburg, Nov. 1978.
15. Baumgartner, E., and Campoy, J. Feeding ⅜" × 0 coal to a heavy medium cyclone. Third Symposium on Coal NCA/BCR Coal Conference, Louisville, Kentucky, U.S.A., Oct. 1977.

Explosives seminars

In his address to members of the quarrying fraternity at Taylor's Travelodge, Alberton, in the first of a series of seminars on the explosives industry, Mr Graham Harrington, AECI's explosives sales manager, said that each mining operation dictated its own special blasting system and technique.

'In South Africa we have unique mining conditions. Therefore, we have to find unique solutions to our problems, with the result that far superior blasting technology is frequently being used here than overseas', he said.

Emphasizing the importance of a good initiation system in blasting techniques, Mr Claude Cunningham, AECI explosives engineer, told the seminar that a proper system would supply better fragmentation and heave, while controlling backbreak, flyrock, airblast, and ground vibration.

Mr Ernie Wright, Senior Inspector of Mines, Pretoria, outlined the basic safety measures and requirements laid down by the Chief Inspector of Mines.

Talking about blasting vibrations and airblast, Mr Ken Derham, AECI explosives engineer, said that good public relations were very important whenever a blast was planned near housing or a built-up area. This required regular informative meetings between the blasting engineer or quarry manager and the people living in the area, explaining to them the precautions taken and the likely effect the blast would have on their personal comfort.

Future seminars, which will deal with the practical use of explosives, the safety of employees, the protection of the environment, and the general comfort of the public, are available to explosives users. For further information contact the Press Officer, AECI Limited, P.O. Box 1122, Johannesburg 2000. Telephone: (011) 21 4651. Telex: 87048 SA.

SAIMM mining vacation schools

Three schools, each of four-and-a-half days, on the subject of increased underground extraction of coal, are being arranged by the South African Institute of Mining and Metallurgy. The object of the Schools is to provide up-to-date information on all aspects of increased volumetric extraction of coal underground. Topics to be covered will include geology, hydrogeology and ecology, the legal implications of maximum extraction, rock mechanics, longwalling, and the numerous methods of pillar extraction. Case studies of practical problems will afford delegates the opportunity of applying the knowledge gained at the School. Delegates will work in teams during the case studies. The course will cover the Natal, Transvaal, and Orange Free State coalfields, and the emphasis will be conceptual rather than detailed. The Schools will be of benefit to the middle and senior management level on mines and at head offices, and officials from the level of Underground Manager upwards should attend.

The dates of schools are as follows: Monday, 26th Jan., to Friday, 30th Jan. Monday, 2nd Feb., to Friday, 6th Feb. Monday, 9th Feb., to Friday, 13th Feb. The schools will end before lunch on the Friday and will be held at the University of the Witwatersrand.

The attendance fees are as follows:

Members of SAIMM	R300
Non-members	R400

A Company Affiliate member is entitled to register two non-members to attend the schools at the lower rate.

The fee covers all costs connected with the School, including course notes, teas, lunches and social functions. It does NOT include the cost of accommodation.

All enquiries should be addressed to The Secretary, S.A. Institute of Mining and Metallurgy, P.O. Box 61019, Marshalltown 2107. (Tel. 834-1271.)