An investigation of the flotation of three South African coals

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SYNOPSIS

An account is given of the procedures used by the South African Iron and Steel Industrial Corporation (Iscor) for tests on the flotation of coal fines, and some of the beneficiation problems encountered with coal from Durnacol, Grootegeluk, and the Soutpansberg area are discussed.

These, and other South African coals differ from overseas coals in that they contain a high percentage of fixed ash, which means that they have to be crushed more finely for liberation and that they then contain more fine material (smaller than 0,84 mm). In addition, the coal from the three areas mentioned occurs in fine layers and seams, and contains many intergrown particles.

SAMEVATTING

Daar work verslag gedoen oor die metodes wat die Suid-Afrikaanse Yster en Staal Industriële Korporasie (Yskor) toepas vir toetse in verband met die flottasie van fynsteenkool, en sommige van die veredelingsprobleme wat met steenkool afkomstig van Durnacol, Grootegeluk en die Soutpansberggebied ondervind word, word bespreek.

Hierdie en ander Suid-Afrikaanse steenkool verskil van oorsese steenkool deurdat dit 'n hoë persentasie vaste as bevat wat beteken dat dit fyner vergruis moet word vir bevryding en dan meer fynmateriaal (kleiner as 0,84 mm) bevat. Verder kom die steenkool uit die drie genoemde gebiede in dun lae voor en bevat baie vergroeide partikels.

INTRODUCTION

The South African Iron and Steel Industrial Corporation, better known as Iscor, is not the only company in this country that currently practises beneficiation of coal fines. However, it was Iscor that pioneered the flotation of coal in South Africa in the early 1950s at the Durban Navigation Collieries (Durnacol or DNC) Mine.

Since the flotation plant at the DNC Mine has been used as a basis for the design of other plants, it forms a good starting point for this discussion, which will include a brief discussion of some of the problems investigated on coals from Iscor's other two deposits, Grootegeluk and Soutpansberg.

Iscor is mainly interested in coking coal for use in its blast furnaces.

It must be pointed out that South African coals differ entirely from British and European coals, in that they contain a high percentage of middlings coal, that is coal with a high content of fixed ash[1]. This is true of the three coal deposits to be discussed, especially Soutpansberg and Grootegeluk. This problem demands finer crushing for liberation, with the resulting formation of a higher quantity of fine material. Up to now Iscor's investigations have shown that flotation is the most successful method for the beneficiation of these fines.

Table I summarizes the most important coking properties for the three coals under discussion and for an imported coal. An ash content of approximately 12 per cent is required for an acceptable coking coal. To evaluate a coking coal is a science in itself and will not be discussed in detail here. Coal from DNC is not a good coking coal by world standards, coal from Grootegeluk can be regarded as a blend coal, and coal from Soutpansberg is a good coking coal.

INVESTIGATIONAL PROCEDURES

Preparation of Samples

The Iscor plants practise heavy-medium separation and flotation, the fines produced being screened on 0,5mm slotted screens for flotation and at 0,84mm for laboratory tests.

Because the coal usually contains large amounts of shale, and also because the coal occurs in layers, the flotation feed consists largely of flat, flaky pieces. Screening on a slotted screen thus allows a larger passing size than would be the case with a square-mesh screen.

A comparison between laboratory-screened and plant-screened DNC material is given in Table II.

Flotation Investigations

For laboratory flotation investigations, quantities of 500g are floated in a standard laboratory flotation machine, water being added to give 40 per cent solids in the cell. Paraffin is then added, and conditioning is vigorous for between 3 and 5 minutes depending on the type of coal. Frother is added 15 seconds before the start of the flotation stage, when the pulp is diluted to 10 per cent solids and the impeller speed reduced to a peripheral speed of approximately 200 m/min. Only one cleaning stage is practised in the laboratory since this is plant practice. The concentrate, middlings, and tailings are then assayed for ash.

The flotation efficiency can be established by a comparison of the flotation results with washability values. Washabilities are obtained from sink–float analysis, a typical example of which is given in Table III. In Fig. I

TABLE I

COKING PROPERTIES OF VARIOUS COALS

Property	DNC	Grootegeluk	Soutpansberg	Imported
Ash content, %	12,0	10,0	12,0	9,5
Volatile matter, %	30	36	22	25
Swelling index	$5\frac{1}{2}$	4	9	8
Roga*	62	50	87	80
Dilatation†	−20 to 0	—	400	100

*The Roga test assesses the caking power of hard coal, the caking power being defined by the mechanical strength of crucible coke obtained by carbonization under standard conditions.

†The dilatometer test is used to determine the coking power of hard coals, and gives a relative measure of the plastic behaviour and wetting characteristics of the coals.

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TABLE II

DIFFERENCE BETWEEN PLANT-SCREENED AND LABORATORY-SCREENED MATERIAL

Size fraction mm	Plant Mass % Frac.	Plant Mass % Cum.	DNC Laboratory Mass % Frac.	DNC Laboratory Mass % Cum.	Grootegeluk Laboratory Mass % Frac.	Grootegeluk Laboratory Ash % Frac.
+0,841	4,1	4,1	—	—	—	—
−0,841 + 0,589	11,2	15,3	22,3	22,3	21,7	40,7
−0,589 + 0,417	17,3	32,6	16,8	39,1	14,9	40,0
−0,417 + 0,295	14,7	47,3	15,9	55,0	13,9	40,6
−0,295 + 0,208	12,0	59,3	12,1	67,1	12,1	42,0
−0,208 + 0,147	11,8	71,1	8,9	76,0	9,6	45,3
−0,147 + 0,104	7,5	78,6	5,5	81,5	6,1	49,0
−0,104 + 0,074	6,6	85,2	3,9	85,4	5,5	46,3
−0,074 + 0,044	4,9	90,1	3,8	89,2	5,2	44,2
−0,044	8,9	100,0	10,8	100,0	11,0	54,5
Total	100,0	—	100,0	—	100,0	43,9

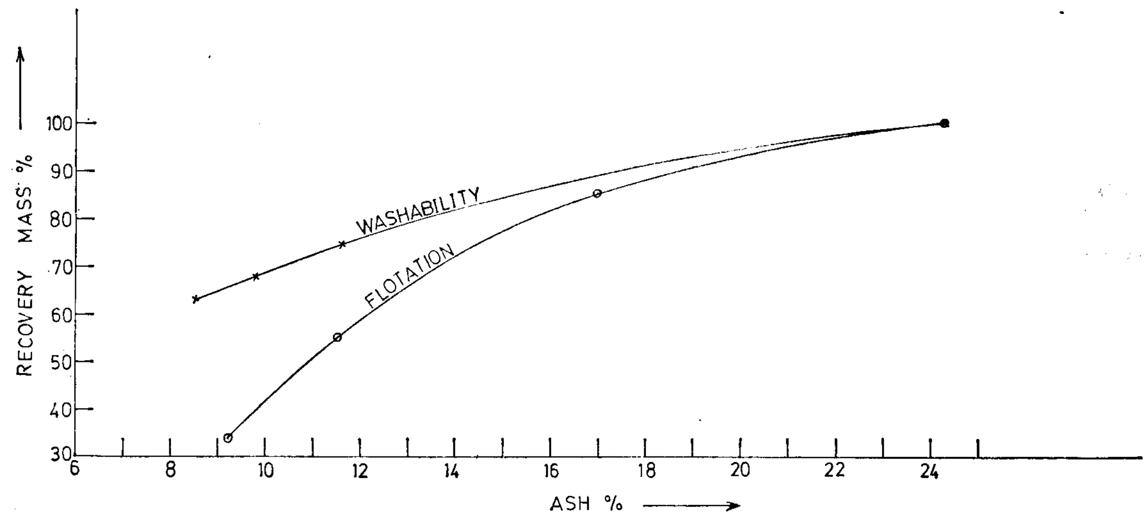

Fig. 1—Comparison between results obtained by flotation and washability values

these values are compared with flotation results obtained on the same feed. The flotation efficiency for a certain grade of ash can be obtained from the curves, and is expressed as a percentage of the theoretical value.

If only small quantities of coal are available, locked batch tests are conducted after the initial individual bench tests. Five tests are usually sufficient to give rise to fairly reliable conclusions.

If enough material is available, continuous pilot-scale runs should be conducted before full-scale plant runs are carried out.

TABLE III

TYPICAL SINK–FLOAT ANALYSIS OF DNC FINES

Product g/cm³	Mass % Frac.	Mass % Cum.	Ash % Frac.	Ash % Cum.
Float 1,5	62,2	62,2	8,5	8,5
1,5 to 1,6	5,6	67,8	24,6	9,8
1,6 to 1,7	5,9	73,7	32,2	11,6
Sink 1,7	26,3	100,0	59,7	24,3
Total	100,0	—	24,3	—

Coal from DNC

The flotation plants installed at DNC are capable of treating a total of more than 100 t/h. Approximately 15 per cent of the final coking coal arises from the flotation sections. The flotation units are $8m^3$ and $3m^3$ in size. A flowsheet is given in Fig. 2.

Shaking Tables

During the design stage of the plant, shaking tables were considered as an alternative to flotation. Investigation showed that the material had to be deslimed before it could be tabled because the high-ash slimes would otherwise report with the bulk of the water in the low-gravity material.

On a feed that had not been deslimed, the tables could not give better ash values than 13,1 per cent with a recovery of 67,5 per cent by mass. The flotation results on this material indicated a recovery of 75,2 per cent at 12 per cent ash.

In an attempt to create favourable conditions for tabling, the minus 0,84mm material was deslimed before further treatment. Because of the high losses of coal in the slimes, the slimes had to be treated by flotation.

Although the combined table and flotation results

TABLE IV

FLOTATION RESULTS FOR VARIOUS COAL SAMPLES

Flotation products	DNC				Grootegeluk				Soutpansberg							
	Plant		Laboratory		Zone 10		Zone 11		Natural–0,84 mm		Primary middlings		Secondary middlings			
													Dry grinding (–0,21mm)		Wet grinding	
	Mass %	Ash %	Mass %	Ash %	Mass %	Ash %	Mass %	Ash %	Mass %	Ash %	Mass %	Ash %	Mass %	Ash %	Mass %	Ash %
Concentrate	47,9	10,2	48,3	10,1	39,7	9,7	28,6	10,5	74,2	11,5	50,0	11,9	10,8	13,6	26,7	12,1
Middling 2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	18,3	25,5
Middling 1	—	—	—	—	23,2	27,8	19,1	29,6	5,2	49,3	22,4	28,5	12,8	29,6	19,9	42,2
Tailing	52,1	38,1	51,7	38,3	37,1	66,8	52,3	75,7	20,6	63,9	27,6	41,8	76,4	39,6	35,1	52,2
Total	100,0	24,7	100,0	24,6	100,0	35,1	100,0	48,3	100,0	24,3	100,0	23,9	100,0	35,5	100,0	34,6
Flotation efficiency, %					74,9		59,0		93,3		71,9		33,4		64,6	

equalled the washability, this method could not be considered for practical reasons. Extremely high flotation retention times had to be employed, probably because of the fineness of the slime feed (approximately 80 per cent smaller than 37μm). Because of the excessive flotation retention time required, a flotation plant for the treatment of these slimes would be as large as a plant where no desliming was employed. It was therefore decided that only flotation should be used for the treatment of the minus 0,84mm material.

Flotation

With the original flowsheet (Fig. 2) it was difficult for acceptable recoveries to be obtained on some plant feeds since coal was sometimes lost in the tailings. Plant results and confirmatory laboratory results are shown in Table IV.

Standard Method

Attempts were made in the laboratory to improve the recovery. Only the concentrations of the reagents were varied during these tests. Table V shows that the recovery of the concentrate could be improved to 57,1 per cent, but that the grade decreased to 12,8 per cent ash. To establish the reason for this inefficiency, sink–float investigations were carried out on the three flotation products (Table V).

On a feed that had not been deslimed, the tables could not give better ash values than 13,1 per cent with a recovery of 67,5 per cent by mass. The flotation results on this material indicated a recovery of 75,2 per cent at 12 per cent ash.

Of the flotation concentrate, 22,7 per cent has an ash content of 29,1 per cent. This material is ultrafine (smaller than 44 μm). Of the flotation middling, 51,5 per cent consists of material with an ash content of 11,4 per cent. In this case, the material is relatively coarse — approximately 0,5 mm. From these results on the concentrate and middling, it is clear that the material of 29,1 per cent ash in the concentrate is more floatable than the low-ash material (11,4 per cent ash) in the middling.

As it was not possible to conduct a proper petrographic

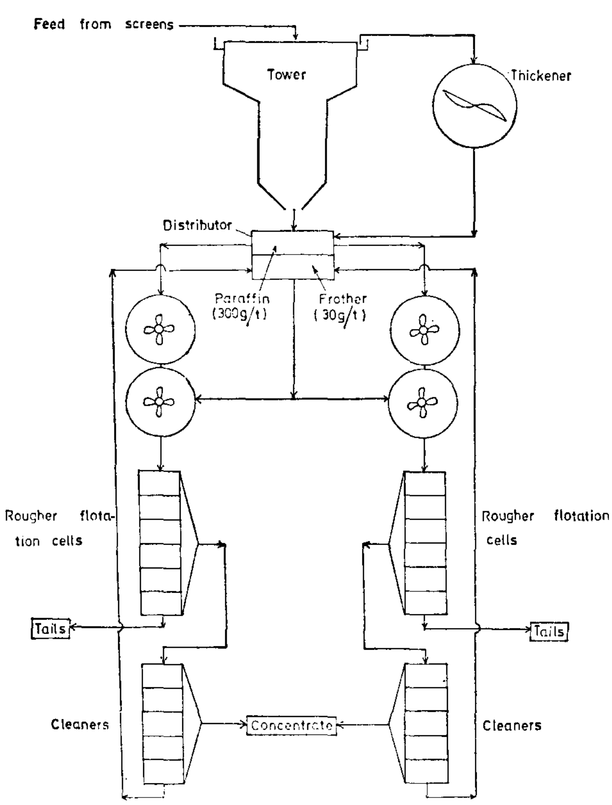

Fig. 2—Flowsheet for the flotation plant at DNC

TABLE V

SINK–FLOAT ANALYSIS OF FLOTATION PRODUCTS FROM DNC COAL

Flotation product	Sink–float products	Mass %			Ash %	
		Sink–float	Flotation feed			
		Frac.	Frac.	Cum.	Frac.	Cum.
Concentrate	Float 1,52	77,3	44,1	44,1	8,0	8,0
	Sink 1,52	22,7	13,0	57,1	29,1	12,8
	Total	100,0	57,1	—	12,8	—
Middling	Float 1,52	51,5	12,2	69,3	11,4	12,6
	Sink 1,52	48,5	11,5	—	47,4	—
	Total	100,0	23,7	—	28,9	—
Tailing	Float 1,52	10,7	2,1	—	15,0	—
	Sink 1,52	89,3	17,1	—	70,5	—
	Total	100,0	19,2	—	64,5	—

investigation of the fine material with an ash content of 29,1 per cent, it was decided to establish the difference in composition between the coarse low-ash fractions in the concentrate and the middling. The results in Table VI show that there was more vitrinite in the concentrate fraction, which is in line with the observations of other investigators[2–4] that vitrinite is more floatable than fusinite. However, from the results reported in Table VI, it is clear that it is difficult in practice to effect a sharp separation between these materials. Some of the fusinite particles float before some of the vitrinite particles, probably due to the difference in particle size.

A more selective method had to be found and various parameters were therefore investigated.

Methods Producing Negative Results

Results with depressants such as Na_2SiO_3, Na_2SiF_6, CMC, guars, and dextrines were very disappointing, and these depressants were found to effect no improvement at all. When various readily available collectors from different suppliers were tested (not the special types mentioned by Vlashova[6] and Petukhov[7]), ordinary kerosene proved to be the best. This is in line with the conclusions of Brown[8], who mentions that a liquid and not extremely viscous paraffinic hydrocarbon having a high molecular mass should be an effective collector for coal. For various reasons of a practical nature power paraffin, which is virtually as effective as kerosene, is used on Iscor's plants.

Only three methods yielded improved results.

Influence of Frother

Tests on frother concentration showed that low concentrations produced better results. Neczaj-Hruzewicz[9] found that increasing frother additions cause a higher ash content in the concentrate. When the frother was omitted completely during laboratory tests, the results were close to washability. However, previous experience proves that it is impossible to run a coal-flotation plant without frother. The reason for this is possibly the flocculation effect of an excessive amount of paraffin[2]. As a result, the froth created is heavily loaded, dry, and brittle, and tends to fall back into the pulp when a fairly large cell is used. As a frother cannot be omitted, starvation quantities of an aliphatic alcohol or a polyglycol type, both of which are conducive to the elimination of gangue[10], are preferred.

TABLE VI

PETROGRAPHIC ANALYSIS OF LOW-ASH PRODUCTS FROM DNC COAL

Product	Ash %	Vitrinite %	Exinite %	Reactive semi-fusinite %	Inert semi-fusinite %	Sclerotinite %
Concentrate Float 1,52	8,0	61	4	18	16	1
Middling Float 1,52	11,4	41	3	30	24	2

TABLE VII

STAGE-ADDITION METHOD ON DNC COAL

Product	Mass %		Ash %	
	Frac.	Cum.	Frac.	Cum.
Concentrate 1	45,1	45,1	11,1	11,1
Concentrate 2	11,2	56,3	12,9	11,5
Concentrate 3	6,6	62,9	15,2	11,9
Concentrate 4	3,6	66,5	17,1	12,2
Concentrate 5	5,7	72,2	20,9	12,9
Concentrate 6	2,2	74,4	25,6	13,2
Concentrate 7	1,2	75,6	29,4	13,5
Concentrate 8	2,0	77,6	35,9	14,1
Tailing	22,4	100,0	64,7	25,5
Total	100,0	—	25,5	—

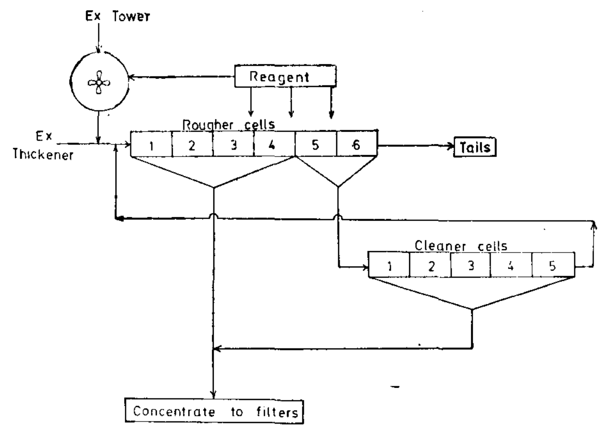

Fig. 3—Flowsheet proposed for the flotation plant at DNC

Influence of Stage Additions

All the reagents were added in eight stages during the flotation process (Table VII). These results show that 62,9 per cent of the mass can be recovered at an ash content of 11,9 per cent, with the possibility of further improvement since these values were obtained with only one stage of flotation, viz the rougher stage. Concentrates 1 to 3 could be removed as a final concentrate, and concentrates 4 to 8 could be treated in a cleaner stage, which could improve the recovery even further.

Influence of Separate Conditioning

In the last method, the finer and coarser fractions were conditioned separately and recombined for flotation. Glembotskii[11] also obtained promising results by this method. In the tests reported here, the plus 0,6 mm material, after being conditioned with reagent, was combined with unconditioned minus 0,6 mm material. The latter received no conditioning at all. This method would be easy to use at the DNC plant, where the tower product consists mainly of coarse material and the material from the thickener is relatively fine.

Proposed Plant Flowsheet

The flowsheet shown in Fig. 3 was based on the results of these investigations. This method is a departure from the standard procedure, and pilot-scale tests will have to be conducted on a more representative sample to verify the laboratory results before plant tests are undertaken.

COAL FROM GROOTEGELUK

Flowsheet

Coal from this area differs from the DNC material in that the ash content is high, averaging about 45 per cent, and relatively finer intergrowths are found. The body consists of various zones, and the testwork was concentrated on material from zones 10 and 11, especially

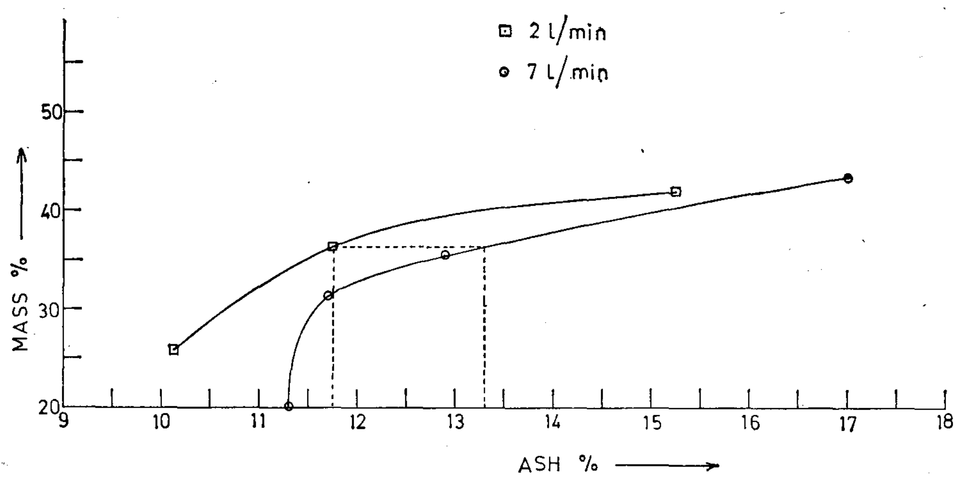

Fig. 4—Influence of air regulation on the flotation of coal from Grootegeluk

the latter, where the ash values are higher. The flotation section of the plant can treat 365 t of feed per hour. Basically, the flowsheet will be the same as at DNC, but larger flotation units (16m³) of a different type are illustrated as rougher cells, and 3m³ units as cleaner cells.

Investigations Conducted

The investigation of Grootegeluk coal started on a laboratory scale, followed by pilot-scale work at Pretoria and on site at Hoornbosch, where Iscor erected a 25 t/h pilot plant. Investigations were also conducted on commercial cells.

Standard Method

As this is a blend-coking coal, it was decided to upgrade it to an ash content of 10 per cent. The results obtained on samples from zones 10 and 11 are reported in Table IV, which shows that the flotation recoveries were much lower than from the DNC material, as could be expected from feeds of higher ash content. Another factor is that this coal is much more intergrown, and the flotation efficiency is therefore relatively low, especially on the sample from zone 11.

Influence of quantity of Air

The regulation of air was also found to be of crucial importance. This was clearly illustrated during laboratory tests, which were confirmed later both on pilot-plant and full-scale units. Fig. 4 represents a typical set of results obtained in the laboratory. From the diagram it is clear that, for the same recoveries, the ash grade was 1,6 per cent better in the tests where relatively little air was used. When flotation units were being selected for the plant and various types of equipment were being tested on a commercial scale, it was found that unrestricted air flow resulted in poor concentrate with an ash content of about 14 per cent, whereas restricted air flow produced concentrates of the desired quality (10 per cent ash). Arbiter[12], during his investigations into air-flow numbers on a zinc ore, also found that the regulation of air improved the results.

Problem of Sedimentation

An aspect that caused concern during these trial runs was the amount of sedimentation in the cells resulting from the high-ash material. As it was known that such problems are encountered[13] in large units (8m³ and larger), it was decided that this phenomenon should be investigated in commercial-size units. Problems were expected with excessive settling of the coarse high ash material, which results in ineffective dispersion characteristics.

Problems were indeed encountered with some types of cells. The sediments were excessive, and speeding up of the rotors resulted in a concentrate with a higher-ash content. In the type of cell preferred, the sediment could be reduced by a reduction in the air flow, which is also beneficial for the ash grade. The air dispersion in these cells was good, and the froth surface was relatively turbulence-free, especially in the smaller units (3m³).

It was decided that water-only cyclones should not be used to remove excessive particles of shale before flotation since laboratory tests had shown that approximately 4 per cent of the coal present in the feed was lost in the cyclone tailing.

COAL FROM SOUTPANSBERG

Laboratory Flowsheet

Soutpansberg coal is virtually the only South African

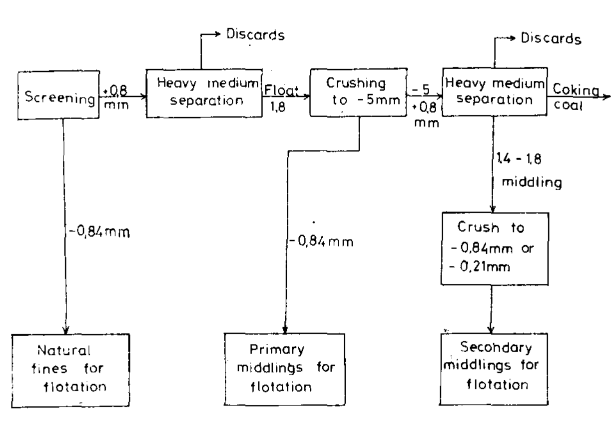

Fig. 5—Preliminary flowsheet for the flotation of coal from Soutpansberg

coal that can be regarded as a good coking coal by world standards. As at Grootegeluk, a rather complicated flowsheet (Fig. 3) must be followed for its recovery, the main problem being the fine intergrowth of particles. Fig. 5 gives a simplified flowsheet. Interesting to note is that 25 per cent of the run-of-mine coal goes to the flotation section.

Results Obtained by the Standard Method

As Table IV shows, flotation efficiencies for the natural product are higher than for the secondary product. It should be noted that the secondary middling had already been crushed to minus 0,21mm. Sufficient liberation could not be achieved when the material was crushed to a particle size smaller than 0,8mm.

Influence of Grinding

Further tests conducted on the secondary middling product involved dry pulverization to minus 0,044mm, which liberated the particles to a large extent, desliming before flotation, and the addition of depressants like Na_2SiO_3. However, Table IV shows that the results improved only when the material was wet ground in a rod mill. A grade of 12 per cent ash could be obtained, and the recovery improved to such an extent that flotation efficiency increased to 64,6 per cent. (Three flotation stages are necessary to give this improved efficiency.) The difference in flotation behaviour due to different grinding techniques can be related to changes in surface reactions[14].

CONCLUSIONS

As this discussion has indicated, the South African coals considered here are difficult to beneficiate, owing, among other things , to the occurrence of the coal in fine layers or seams. This phenomenon results in high-ash flotation feeds that consist mainly of particles of shale and coal. Flotation is one of the most efficient and practical methods for the beneficiation of such fine coal. Thus, the abundance of coal in South Africa, and the recent emphasis on the briquetting of coke-oven charges indicate that coal flotation has a sound future in this country.

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