COALTECH 2020

Task 4.11.1

Dense-Medium Fine Coal Processing: Tests conducted at South Witbank Coal Mine

by

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1. INTRODUCTION

The Coaltech 2020 fine coal dense-medium pilot plant was taken out of commission at Koornfontein Colliery on Friday, 7 June 2002. This was done to enable the plant to be dismantled and moved to South Witbank Coal Mine (SWC) where it was to be tested on fine coal from the No. 4 Seam.

The plant was re-commissioned at SWC on 18 September 2002.

The move from Koornfontein to SWC took much longer than originally anticipated. Problems were also experienced with the availability of a crane and a low-bed. This caused a three-week delay in moving the plant. Moreover, an amount of R14 000 had to be spent on renting an additional crane and low-bed. It is believed that the root cause of the problem was poor communication between JHDA and Koornfontein Engineering. It was agreed that in future, to prevent the recurrence of such a problem, all communication regarding matters such as this should be done in writing.

Several changes were made to the configuration of the plant during its reconstruction at SWC, specifically as follows:

- It was decided to leave the Fast Screen out of the circuit because the unit was found to be unable to provide the required capacity. The unit was returned to Delkor. Appreciation for Delkor's contribution was recorded in a letter to the company.

- Two 350 mm-diameter dewatering cyclones were installed in place of the Delkor Fast Screen to deslime the feed coal. The cyclones were kindly made available for the project by Mr Thys Horn of Metquip.

- The tank and pump previously used to pump the minus 100 micron slimes to the thickener were converted to serve as the dewatering cyclone feed pump.

- The two magnetic separators were swapped around, i.e. the Malvern unit was installed as the product magnetic separator and the Magnapower unit was installed on the discard side.

- The dirty water tank and pump were removed from the circuit and the sinks magnetic separator overflow routed to the discard tank.

- Product and discard dewatering cyclones were installed ahead of the existing SWC dewatering screens.

- The discard pump was initially speeded up to cope with the increased pumping head. This did not prove successful and the 3/2 Warman pump was replaced with a 4/3 Warman taken from the dirty water tank.

- The densifier cyclone was removed from the circuit because it was not functioning as a densifier at the low circulating medium relative densities employed in the plant.

- The product magnetic separator over-dense medium was routed to the floats cyclone mixing-box to reduce the difference in feed density between the primary and the floats cyclone.

- A 120 mm spigot was fitted to the primary cyclone and a 100 mm spigot to the floats cyclone. This is the original design configuration.

- The cyclone feed pressures were set at 12D as per the original design.

The plant is shown in the new location at SWC in the following photograph (Figure 1).

Figure 1: Photograph of the test plant at SWC

2. EARLY RESULTS AT SOUTH WITBANK

Initial test runs at SWC were disappointing. Although the yields achieved were very good, the product quality did not meet the target calorific value (CV) of 28 MJ/kg (air-dry basis). Values of between 26 and 27 MJ/kg were recorded.

Washability data for the minus 2 mm size fraction from SWC shows that a cut-point density of 1,50 is required to produce a 28 MJ/kg product. At this density, the coal contains more than 40% near-density material. This makes it an extremely difficult separation to achieve. It was clear that the cut-point densities obtained in the plant were too high – thus resulting in the low CV values of the product coal produced, even when the circulating medium density was controlled at very low values.

3. NUMBER OF PROCESSING STAGES AND THE INFLUENCE OF RECIRCULATING LOAD

As part of the test programme at SWC, a series of tests was conducted with the plant in single-, double- and triple-stage mode. The aim of these tests was to establish whether it would be possible to obtain the required product quality with only a single stage of processing. The motivation for this is the fact that a single-stage plant is the simplest to operate and no recirculation of intermediate products is necessary. This has obvious advantages from the perspective of plant operation and throughput.

Parallel to the plant tests, computer simulation runs were conducted to gain a better understanding of the results obtained from the plant.

The results obtained from the simulation are summarised in the following graph.

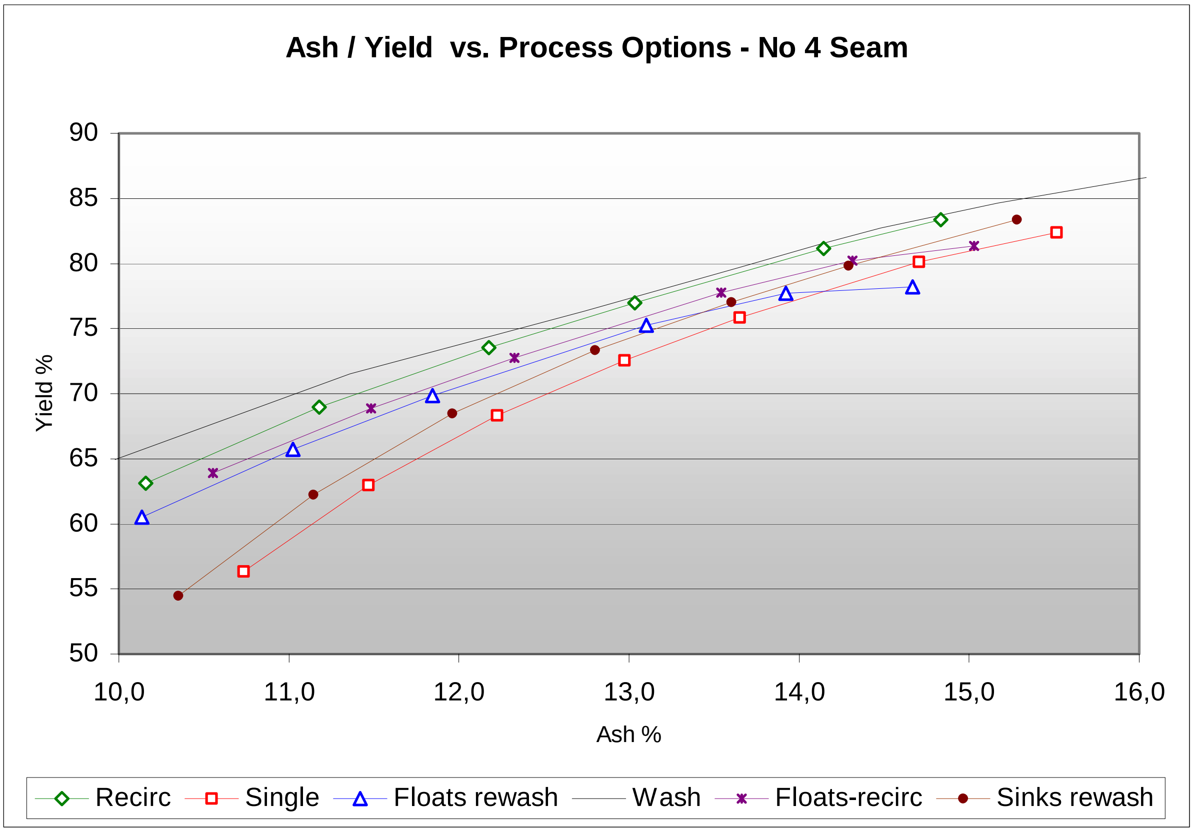

Figure 2: Summary of simulation results

The results shown in Figure 2 indicate that the best yield should be obtained when using all three cyclones with full recirculation of intermediate products. Reprocessing only the float product from the primary cyclone and recirculating the sinks from the rewash cyclone is the next best option. Reprocessing of only the sink material from the primary cyclone is the next-to-worst option, only slightly better than single-stage processing.

The results obtained from the plant tests showed that a single cyclone, with no recirculation of intermediate products, is not able to produce the required product quality of 28 MJ/kg.

Typical results obtained from the plant when using only a single cyclone are shown below in Table 1.

Table 1: Single-stage processing results (11/10/2002)

Circulating medium RD	Product ash (%)	Product CV (MJ/kg)	Yield (%)
1,200	20,2	25,45	84,7
1,225	17,8	26,07	77,6
1,250	20,7	24,71	89,7
1,300	16,8	26,52	80,7

It can be seen from Table 1 that product ash values are high and variable. The corresponding CV values are much lower than the target value of 28,0 MJ/kg. The variation in the product quality can in part be attributed to variations in the feed washability and also in the feed size consist. The variation in feed coal quality was noted during operation of the plant. It was further confirmed from the washability data obtained during efficiency testing.

It was not possible at all to produce a 28,0 MJ/kg product from the plant using only one cyclone. The reason for this is believed to be the fact that an EPM value of about 0,06 or better is required to 'reach' a 28,0 MJ/kg product within a single processing stage. The EPM obtained from the single cyclone is thought to be more than 0,08. This was not quantified by an efficiency determination. Efficiency tests, conducted later with the plant operating in two-stage mode, indicated EPM values in the order of 0,08 for the two cyclones combined. It is therefore quite likely that the EPM for a single cyclone will be worse than 0,08.

Spirals, with typical EPM values of 0,20, cannot produce a 28,0 MJ/kg product for the same reason.

This concept is illustrated, using computer-simulated values, in Figure 3 below.

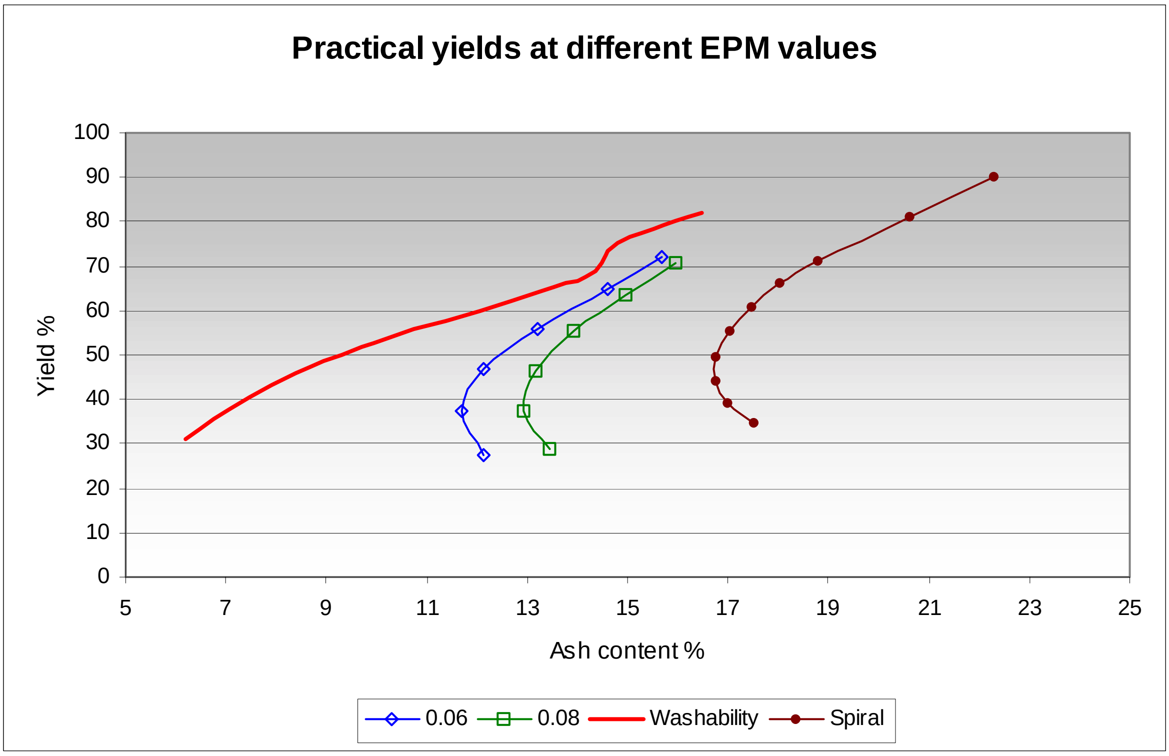

Figure 3: Graph showing effect of EPM on product quality

From Figure 3, one can see that a separation process with an EPM value of 0,06 will be able to produce a product with an ash content of about 12,0%. The process with an EPM value of 0,08 will not be able to achieve a product with an ash content of lower than 13,0%. A spiral will be limited on this coal to a 17,0% ash content product.

Tests conducted with the plant utilising all three cyclones, i.e. the primary, floats and sinks cyclones as per the original design, were also unsuccessful in producing the required product quality.

Although the plant should produce the sharpest separation when utilising all three cyclones, it appears that the recirculation of a discard fraction, arising from the sink cyclone overflow, results in high product ash values being obtained (see Table 2).

Table 2: Three-stage processing results (18/10/2002)

Circulating medium RD	Product ash (%)	Product CV (MJ/kg)	Yield (%)
1,200	18,5		75,2
1,230	17,7		67,3
1,300	19,2		78,8
1,330	20,4		64,7

Control of the relative density of the three individual feed streams is very important and is the critical factor in controlling the amount of coal recirculated within the system.

For the lowest amount of recirculating load, the densities of the primary, floats and sinks cyclones should be equal. Because classification of the medium occurs within the cyclones, the feed density of the floats cyclone tends to be much lower than that of the primary cyclone since it consists mainly of the primary cyclone's overflow medium. The feed to the sinks cyclone, on the other hand, consists mainly of the primary cyclone's underflow medium, and therefore tends to have a high density.

If the plant is operated normally, without any effort being made to reduce the difference in the feed relative densities of the three cyclones, a large recirculating load builds up within the circuit. This was experienced during tests at Koornfontein. It was found that, even at feed tonnages as low as 10 tons per hour, the circuit became 'overloaded' as a result of the circulating load. The first indication of this situation was noted as 'roping' of the floats cyclone underflow.

The influence that the difference in cyclone feed densities has on the circulating load is shown in Figure 4 below.

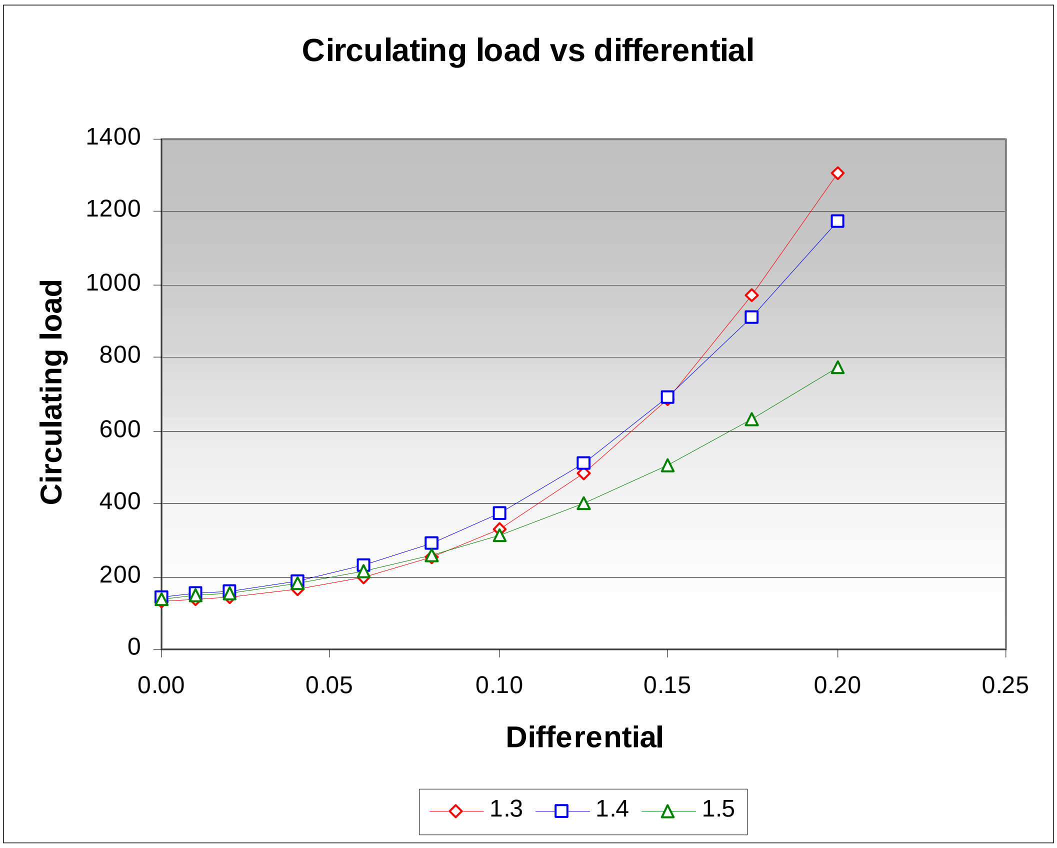

Figure 4: Circulating load vs. differential

The recirculating load consists of floats cyclone underflow material and sinks cyclone overflow material. Sampling of these streams has shown that the two streams contain coal of approximately the same, relatively poor, quality. At Koornfontein this material contained approximately 35% ash.

When the relative density of the feed to the floats cyclone is the same as that of the primary cyclone, or ideally, if the two cyclones cut at the same relative density, only the misplaced material from the floats cyclone will report as 'sinks' in the floats cyclone. The same holds for the sinks cyclone where the 'product' should comprise only the misplaced material from the primary cyclone underflow.

The only available means of controlling the circulating load is to add a controlled amount of the over-dense magnetite from the product magnetic separator to the floats cyclone mixing-box. This increases the relative density of the medium pumped to the floats cyclone, thereby reducing the amount of material reporting to the floats cyclone underflow which is then recirculated to the primary cyclone feed.

In the original plant design, a densifier cyclone was installed to carry out this function. It was, however, found that at the low circulating medium densities employed, the densifier cyclone did not function as intended and it was therefore removed from the circuit.

The sinks cyclone feed density has to be reduced by adding water to the sinks cyclone mixing-box.

Both the addition of over-dense magnetite to the floats cyclone feed and the addition of water to the sinks cyclone feed have to be done and controlled manually. This is obviously not easy and, in a full-scale plant, will require automation.

Nonetheless, even when the densities of the three cyclones were controlled relatively close together, the product from the plant was still found to be high in ash content and low in CV. It may be speculated that the amount of high-ash coal 'trapped' in the recirculating load somehow contributes to this.

Tests were also conducted with the plant in 'double-stage' mode. This implied taking the sinks cyclone out of the circuit and routing the primary cyclone underflow directly to the discard magnetic separator. The primary cyclone overflow material is reprocessed in the floats cyclone. The relative density of the feed to the floats cyclone is controlled, as previously described, by adding the over-dense medium from the product magnetic separator to the floats mixing-box.

Routing the over-dense medium from the magnetic separator to the mixing-box proved somewhat difficult since very limited height was available for a gravity-based system consisting only of a chute. The medium gravitated well enough most of the time, but on numerous occasions it blocked the chute, with the result that the medium overflowed the chute and spilled into the basement. This was especially a problem when the plant was operating at higher relative densities. In a future configuration, it would be advisable to use a pump to transfer this medium. It would then also be easier to control the rate of addition of this medium to the floats cyclone feed for the purpose of controlling the feed medium relative density.

With all over-dense medium from the product magnetic separator reporting to the floats cyclone mixing-box, the relative density of the feed to the floats cyclone was close enough to that of the primary cyclone to keep the recirculating load within acceptable limits. The plant was easily able to process all the fine coal from one of the four main plant modules. This was measured to be about 25 t/h - the design capacity for the plant. A photograph showing the typical load on the feed dewatering screen is shown below in Figure 5.

Figure 5: Feed dewatering screen under load

The test results obtained with the plant operating in 'double-stage' mode were encouraging and product qualities very close to the target value of 28,0 MJ/kg were obtained.

It was, however, still obvious that the actual cut-point density of the combined cyclone pair was much higher than the density of the circulating medium. It was necessary to run the plant with very low circulating medium densities in order to obtain product qualities in the required range of CVs. The data in Table 3 illustrate this.

Table 3: Double-stage processing results (24/10/2002)

Circulating medium RD	Product ash (%)	Product CV (MJ/kg)	Yield (%)
1,10	10,9	28,46	45,1
1,13	14,5	26,81	56,8
1,15	14,0	27,38	62,8
1,17	13,9	27,56	55,2
1,20	14,3	27,30	63,7
1,30	17,3	26,44	72,3
1,40	21,0	24,61	77,2

From Table 3, it is clear that the circulating medium density at which the required product quality could be obtained is extremely low.

One should, however, keep in mind that it is not the relative density of the circulating medium that controls the actual density of separation in the dense-medium cyclone, but rather the relative density of the feed pulp into the cyclone.

When the plant was operated at a circulating medium density of 1,24, the feed medium pumped to the primary cyclone had a relative density of about 1,32 and the feed medium pumped to the floats cyclone a density of approximately 1,28. These readings were recorded on 22 November 2002 whilst taking samples for the second efficiency test.

The relative density of the feed pulp pumped to the cyclones also depends on the relative proportion of coal in the pulp. The higher the feed tonnage into the plant, the lower the density of the feed into the cyclones becomes. Ideally, one should therefore monitor and control the relative density of the feed medium to each of the cyclones, rather than that of the circulating medium. However, at present, it is only the circulating medium density that can be measured and controlled.

A density-measurement device has been obtained on loan from Debex and installed on the primary cyclone feed pipe to assist in monitoring the relative density of the feed pulp to this cyclone. This device, however, is still not functional and changes to the software are required in order to render the unit suitable for application to coal. Debex has been contacted in this regard and is looking into the matter.

A further factor that needs to be kept in mind is that the difference between the feed medium density and the actual density of separation, i.e. the so called 'differential', becomes larger as the size of the coal particles to be separated becomes smaller. When fine coal is being processed, as is the case here, the differential could be very high.

The following graph, Figure 6, depicts the relationship between particle size and differential.

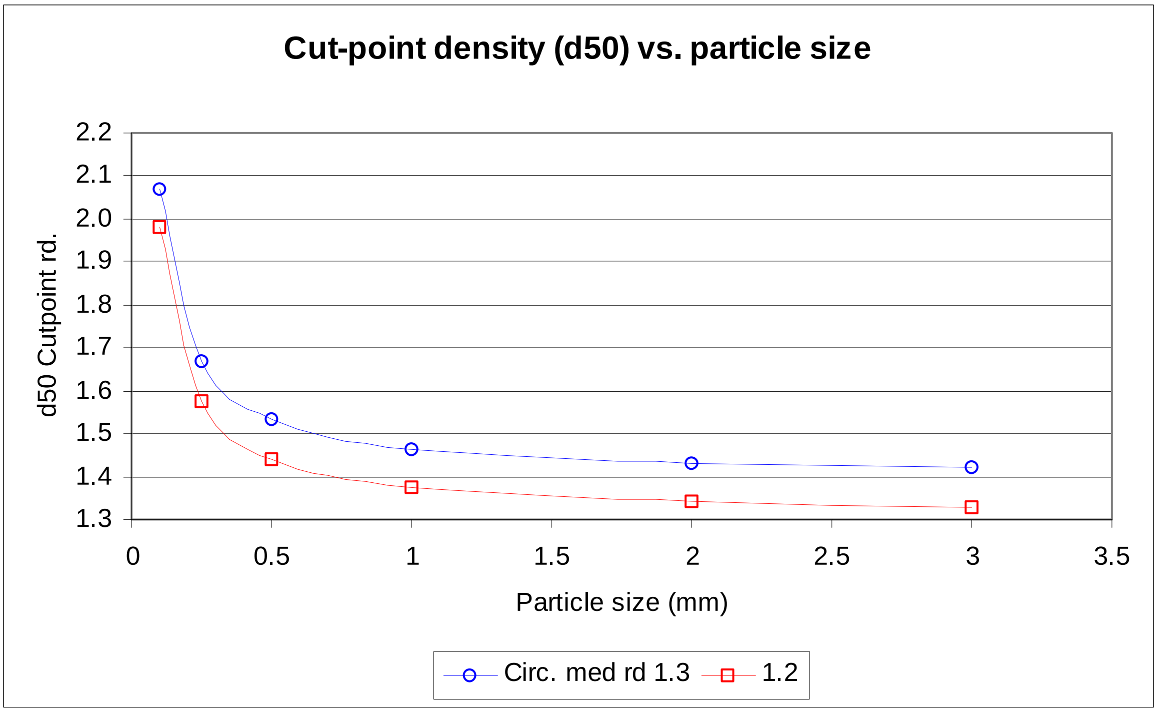

Figure 6: Effective cut-point density vs. particle size

In order to reduce the differential between the circulating medium density and the actual cut-point density, the following additional actions were taken:

- Superfine magnetite from Martin & Robson was used in the circuit.

- The cyclone spigot on the primary cyclone was increased from 120 mm to 145 mm and the spigot on the floats cyclone was increased from 100 mm to 120 mm.

- The feed pressure of the primary and floats cyclones was lowered to 9D.

These actions reduced the differential between the circulating medium density and the cut-point density. The following results were obtained after the above changes had been made to the plant (Table 4):

Table 4: Double-stage processing results (4 & 5/11/2002)

Circulating medium RD	Product ash (%)	Product CV (MJ/kg)	Yield (%)
1.300	16.3	26.71	69.8
1.250	13.9	27.68	58.2
1.200	11.0	28.46	45.8
1.150	11.7	28.47	22.7
1.200	12.0	28.59	50.3
1.225	11.8	28.27	44.3
1.250	14.6	28.63	34.7
1.275	13.7	27.95	57.4

Following the above tests, the plant was run at a set circulating medium density for an extended period and the product sampled to ascertain that the correct quality of product can be produced consistently. The following results were obtained (Table 5):

Table 5: Continuous run results

Date	Circ. medium RD	CV (MJ/kg)	Ash content (%)
11 Nov	1,25	27,29	13,4
11 Nov	1,25	27,95	12,6
11 Nov	1,25	27,79	13,3
11 Nov	1,25	27,73	11,9
11 Nov	1,25	26,97	14,4
11 Nov	1,25	27,13	14,2
14 Nov	1,25	27,99	12,8
14 Nov	1,25	27,58	14,0
14 Nov	1,25	27,61	13,3
15 Nov	1,23	26,70	14,9
15 Nov	1,23	26,78	14,9
15 Nov	1,23	26,66	15,0
15 Nov	1,23	26,60	14,3
15 Nov	1,23	27,07	15,2
15 Nov	1,23	26,60	-
18 Nov	1,21	27,94	-
18 Nov	1,21	27,13	-
18 Nov	1,21	27,81	-
18 Nov	1,21	27,34	-
18 Nov	1,21	27,16	-
18 Nov	1,21	27,61	-

As can be seen from the above table, the product quality varied but stayed within reasonable limits.

A simplified flow diagram of the plant in 'double-stage' configuration is shown in Appendix A.

4. PROBLEMS EXPERIENCED

On a few occasions, the main SWC plant experienced a problem with screen panels on the desliming screens falling out. This caused coarse coal to be pumped to the classifying cyclones. The resulting blockage led to coarse coal in the feed to the dense-medium fine-coal test plant.

Coarse coal also spilled into the clarified water tank, which in turn caused the 50-mm clarified water line to the test plant to become blocked. Initially, the water supply from the main plant could not be isolated and clearing of the blockages was most difficult. The installation of a cut-off valve in the main water-supply line solved this difficulty. The latter also made control of the rates of water addition to, for example, the magnetic separators much easier since it was now possible to leave all the valve settings at the required levels when shutting down the plant.

In future configurations, a guard screen before the fine coal plant, as well as an in-line water filter, need to be installed to avoid such problems.

5. SAMPLING

Samples of the product and discard from the plant were initially taken from the dewatering screens. It was, however, found that a large proportion of especially the finer fractions of the product and discard was lost through the screens. It was therefore decided to revert to taking samples at the magnetic separator effluent discharge point. The samples taken from the magnetic separator effluent contain a low percentage of solids and they were therefore collected in plastic buckets. The samples were allowed to stand for about an hour, after which time the water was decanted to render the samples handleable.

6. ANALYSIS OF SAMPLES

Most of the samples taken were sent to Mpunzi Laboratory for ash content and CV determination.

Those taken for efficiency analysis were sent to Witlab cc.

7. MAGNETITE

Tests were conducted using superfine magnetite from both Martin & Robson (M&R) and Idwala.

Samples of magnetite were taken from the circulating medium and sent to Martin & Robson for size analysis.

Louis van Wyk of Martin & Robson offered the services of their Malvern Mastersizer at no cost. This proved a very valuable contribution to the project as it was possible with this instrument to obtain rapid, repeatable size analyses of magnetite samples taken from the circuit.

From the samples taken and analysed, it was evident that, as was the case at Koornfontein, the magnetite becomes coarser in circuit. The following table (Table 6) shows a summary of magnetite size analysis data for samples withdrawn from the circuit at different intervals.

Table 6: Size consist of magnetite in circuit

Sample	% minus 45 micron	% minus 10 micron)
Raw M&R superfine	81,6	24,9
After 3 days in circuit	74,7	19,7
After 17 days in circuit	72,7	17,7
After 30 days in circuit	65,8	15,2

Analysis of magnetite samples recovered from the magnetic separator underflow showed that the magnetite lost from the circuit was finer than the magnetite in circuit. The magnetite contained in the feed coal to the plant, on the other hand, was found to be very coarse. This is not totally unexpected since this magnetite has already passed through two stages of hydro-cyclones. The net effect of the fine magnetite lost and the coarse magnetite entering the plant would therefore be the coarsening of the magnetite in circuit.

Table 7 below shows the relative size consist data for the magnetite entering the plant in the feed coal and the magnetite lost in the magnetic separator underflow.

Table 7: Size consist of incoming and lost magnetite

Sample	% minus 45 micron	% minus 10 micron)
Magnetite in feed coal	45,9	5,5
Magnetite lost via magnetic separators	85,7	30,1

As was the case at Koornfontein, it was found that it was rarely necessary to add make-up magnetite to the circuit. This would seem to indicate that the magnetite lost from the circuit was being replaced by the magnetite in the feed.

8. EFFICIENCY TESTS

Four separate efficiency tests were conducted on the plant. The first test was done on 20 November 2002 and a second test was conducted two days later on 22 November 2002.

At the time of the first two tests, magnetite from Martin & Robson was used. Idwala magnetite was used during the subsequent two tests conducted on 4 December 2002 and 30 January 2003 respectively. The first three tests were all carried out with the plant operating at a feed pressure of 9D. At the time of the fourth test, the plant was operating at a feed pressure of 18D.

During Test 1, the feed coal was of a very poor quality. This is reflected in the low yield (47,0%) and the low organic efficiency (69,1%) recorded during the test. The feed coal sampled two days later was of a much better quality and both the yield and the organic efficiency recorded were much improved.

Both tests showed relatively large differentials. The circulating medium density was 1,31 for Test 1 and 1,24 for Test 2. The corresponding cut-point densities were found to be 1,57 and 1,64 respectively.

The third test was carried out immediately after the magnetite circuit had been completely cleaned out and refilled with fresh superfine magnetite from Idwala. The circulating medium relative density at the time of this test was 1,25. The cut-point density obtained for this test was low at 1,38, which seems to confirm that fine magnetite reduces the differential between the circulating medium density and the cut-point density.

The EPM values for all three tests were rather disappointing. EPM values of between 0,08 and 0,10 were recorded.

It was thought that perhaps the low feed pressure employed, namely 9D, could be partly to blame for the poor EPM values and so it was decided to increase the feed pressure to 18D for the next efficiency test. It was further decided that the samples for the next test should be screened into three size ranges for analysis.

The fourth test was conducted on 30 January 2003. The circulating medium density at the time of sampling was 1,30.

The results obtained from this test indicated that the coarser size fractions were beneficiated reasonably well, but that the separation of the finest (minus 300 micron) size fraction was poor. It would therefore seem, based on the results obtained, that it may be beneficial to reconsider the size at which desliming of the feed coal is carried out.

The results obtained from the four tests are summarised below in Table 8 and the results obtained for the fourth test are shown in Table 9.

Table 8: Summary of efficiency test results

EFFICIENCY TEST RESULTS Coaltech fine coal plant South Witbank Coal Mine	Test 1 20-Nov-02	Test 2 22-Nov-02	Test 3 4-Dec-02	Test 4 30-Jan-03
Feed ash (%)	31,5	19,4	29,3	27,9
Product ash (%)	17,6	13,2	13,1	8,5
Discard ash (%)	43,8	42,8	35,8	47,7
Product yield	47,0	79,1	28,6	50,5
D50	1,5678	1,6395	1,3864	1,5129
EP	0,1087	0,0984	0,0830	0,0901
Organic efficiency	69,1	89,8	46,1	83,9
Sink in float	9,98	3,70	12,34	5,10
Float in sink	14,26	8,09	7,26	10,56
Total misplaced	24,24	11,79	19,60	15,66

Table 9: Detailed results for Test 4

Efficiency Test Results - Coaltech Fine Coal Plant **Test 4 @ SWC - 30 January 2003**				
	+ 0,5 mm	**- 0,5 + 0,3 mm**	**- 0,3 mm**	**Combined**
% of feed	48,5	26,8	24,7	100,0
Feed ash (%)	22,5	26,3	40,2	27,9
Product ash (%)	6,5	8,2	12,2	8,5
Discard ash (%)	47,1	42,7	52,1	47,7
Product yield	60,6	47,5	29,8	50,5
D50	1,4520	1,5087	1,5077	1,5129
EP	0,0240	0,0587	0,0975	0,0901
Organic efficiency	94,3	75,9	59,9	83,9
Sink in float	0,61	2,03	10,13	5,10
Float in sink	4,82	14,02	15,06	10,56
Total misplaced	5,44	16,05	25,19	15,66

9. FLOAT-AND-SINK ANALYSIS

A rapid method of carrying out float-and-sink analysis on fine coal was developed in co-operation with Mr Pat Fogarty of Witlab cc.

The method employs a ‘cumulative’ approach to performing the float-and-sink analysis as opposed to the conventional ‘fractional’ approach.

The float-and-sink work required for an efficiency test can now be completed in about two or three days. Previously the work took about two weeks to complete.

10. CONTINUOUS OPERATION

Lights were installed in the plant to allow continuous operation. During the second week of December 2002, the plant was run continuously for three days without any problems.

Further extended runs were done during January 2003. These runs were sometimes interrupted by operational problems in the main plant, but very seldom due to problems in the test plant.

11. FUTURE WORK

A number of issues remain to be addressed, perhaps the largest of which is control of the cut-point relative density. At present, only the circulating medium density can be controlled. To achieve full control of the separating density, the medium pumped to the individual cyclones needs to be measured and controlled.

To enable measurement and control of the relative densities of individual feeds, density measurement devices on each feed line would be required. The Debex gauge may well serve this purpose. This type of gauge has the advantage of not requiring any nuclear source to function.

It would further be necessary to control the addition of over-dense medium to the floats mixing-box by way of an automatic actuator, coupled to the density measurement gauge.

When the sinks cyclone is utilised, water would need to be added to the sinks mixing-box via an automatic valve, linked to the density measurement device.

With such an arrangement, it should be possible to control both the cut-point density and the recirculating load.

It would further be necessary to control the size consist of the magnetite in circuit. A source of very fine magnetite must be found to allow the superfine magnetite in the circuit to be ‘topped up’ while some of the coarse medium is bled from the circuit. It would be possible to obtain very fine magnetite from the main plant by installing a small cyclone in the dilute circuit and routing some of the cyclone overflow to the fine coal plant. Some of the sinks cyclone (or primary cyclone if the sinks cyclone is not in circuit) underflow medium can be bled back to the main plant. This underflow medium should be coarser than the rest of the medium in the circuit due to the classification effect within the cyclone.

To make this a workable solution, one would also need to monitor the size consist of the medium in the circuit on a regular basis, but no in-line size-monitoring systems are available yet. The Malvern Mastersizer has proved to be a very useful instrument, however, and may well serve to allow regular monitoring, albeit on a batch-wise basis, of the size consist of the medium in circuit.

Dewatering of the final product is and will remain a critical factor. Techno-economic studies of different fine coal beneficiation options for SWC show that dewatering of the product is as important as the beneficiation step. Thermal drying of the product coal may well feature in a future fine coal beneficiation plant.