COALTECH 2020

Dense-Medium Beneficiation of Fine Coal: Coaltech 2020 Pilot Plant

G J de Korte

Division of Mining Technology
CSIR

Project 4.11.1

March 2002

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

During 2000, following the initial work carried out on re-evaluating the potential of dense-medium beneficiation of fine coal, the Coal Preparation sub-committee decided to construct a pilot plant to enable dense-medium beneficiation of fine coal to be evaluated on a practical scale.

The proposal was put forward to the Coaltech 2020 Steering Committee and approval for the project was obtained.

A concept flow sheet for the envisaged plant was developed by the project team, under the leadership of David Tudor and the technical guidance of Brian Bowes. The flow sheet for the proposed plant was unique in the sense that it proposed the use of three dense-medium cyclones, operating in a “rougher-cleaner-scavenger” mode.

The objectives for the design of the pilot plant were that “large” cyclones should be used, that commercially available magnetite should be used and that the plant should be “easy to operate”.

A number of South African process engineering companies were invited to comment on the proposed flow sheet and to submit tenders for the construction of a 25 t/h pilot plant. The original scope of the work, as issued to the contractors, is attached as Appendix A. The concept flow sheet is also contained in this appendix.

A meeting was held on 22 February 2001 at CSIR Miningtek with representatives of the companies who had expressed an interest in participating in the proposed dense-medium cyclone pilot plant project.

The following people were present at this meeting:

D Tudor	AngloCoal
B Bowes	AngloCoal
J de Korte	CSIR
J Beukes	Coaltech 2020 Programme Manager
M Salter	DRA
E Dubberley	DRA

D M Peatfield	SSP & Associates
M Fox-Martin	SSP & Associates
Frank Joubert	LTA Process Engineering
Marco Allais	LTA Process Engineering
Jim Harrison	JHDA
M Cresswell	Bateman Engineering Ltd
T Bookless	Debtech Process Engineering.

Following from the meeting, proposals were received from Dowding, Reynard & Associates (DRA), Grinaker-LTA and Jim Harrison Design Associates (JHDA). After due consideration, the contract to design and construct the pilot plant was awarded to JHDA.

A number of local equipment suppliers were approached regarding participation in the project. The following suppliers volunteered equipment for the plant on a “free-on-loan” basis:

- Magnapower and Malvern Engineering each supplied a magnetic separator.
- Multotec supplied the required dense-medium cyclones, as well as the densifier cyclones.
- Delkor offered the use of a Delkor Fast Screen for de-sliming of the plant feed.
- Warman supplied all the pumps for the plant.
- Process Automation provided and installed a density controller.

The pilot plant was designed to be modular so that it could be transported to different sites for testing.

The plant was constructed at Black Wattle Colliery just outside Middelburg. On completion, the plant was moved to Koornfontein Colliery, the first test site for the plant.

The plant was commissioned on 5 November 2001 and the first coal was processed through the plant on 13 November.

A view of the completed plant is shown in Figure 1.

Figure 1: View of the pilot plant at Koornfontein Colliery

2 PLANT OPERATION TO DATE

2.1 Mixing boxes

Initially, when the plant was first run with magnetite in circuit, it was found that the primary cyclone feed pump was surging. The orifice in the mixing box had to be enlarged to eliminate the problem.

2.2 Magnetic separator water split

The product and discard magnetic separators initially shared the “dirty water” tank. It was, however, noticed that the overflow from the product magnetic separator contained some product coal and the overflow from the discard magnetic separator contained some discard coal. Combining the two overflows in the dirty water tank and then pumping this water back to both of the magnetic separators caused contamination of both the product and the discard.

It was therefore decided to dedicate the dirty water tank to the discard magnetic separator and to direct the product magnetic separator overflow to the product tank.

2.3 Delkor Fast Screen

A very important aspect of the design of the plant is the use of the Delkor Fast Screen (DFS) to de-slime the feed to the plant. The removal of the minus 100 micron material from the plant feed is believed to be critical to the proper separation of the fine coal into a product and a discard and also for the efficient recovery of magnetite.

When the plant was initially commissioned, the DFS was not yet equipped with a screen cloth. The pilot plant feed, taken from the existing Koornfontein No. 2 Plant spiral feed circuit, was routed directly onto the dewatering screen. This did not prove very successful because the feed stream is relatively dilute at about 25 to 30% solids. The dewatering screen could not handle the amount of water in the feed and the feed rate had to be drastically reduced to about 5 t/h.

The DFS was commissioned on November 22. This allowed the feed tonnage to be increased to about 10 t/h, which proved to be the maximum capacity of the DFS at the time.

Delkor investigated and found that both the carrier belt and the screen cloth installed on the DFS were not of the correct size. The cloth eventually tore on 7 February. A new cloth and carrier belt of the correct size were installed on 18 February. This allowed the tonnage fed into the test plant to be increased to 16 t/h.

Although the full No. 2 Spiral Plant feed can be fed to the DFS, a portion runs over the edges of the screen and reports to the DFS underflow.

The DFS removes approximately 50% of the minus100 micron material in the plant feed.

The following table summarises the result of a test conducted on the DFS on 18 December 2001.

Table 1: DFS performance on 18 December 2001

Screen size (micron)	*% in DFS feed*	*% in DFS product*
+500	20,2	33,5
+212	36,5	38,5
+150	9,4	8,3
+106	5,3	4,9
-106	28,6	14,8

At the time of writing of this report, the capacity of the test plant is still constrained to about 16 t/h by the DFS.

Possible solutions have been discussed with Delkor. Changing the aperture size from the existing 125 micron to 200 micron has been suggested as a potential solution.

2.4 Product quality

Regular samples of the plant feed, product and discard are taken when the plant is in operation. These samples are sent to the Koornfontein laboratory where they are filtered, dried and subjected to ash content and CV determination. The plant yield is calculated from the ash contents of the feed, product and discard using the ash balance method.

The following graph shows the results obtained from the samples taken to date in comparison with the feed coal washability. The different colour points denote samples taken at different cyclone feed pressures.

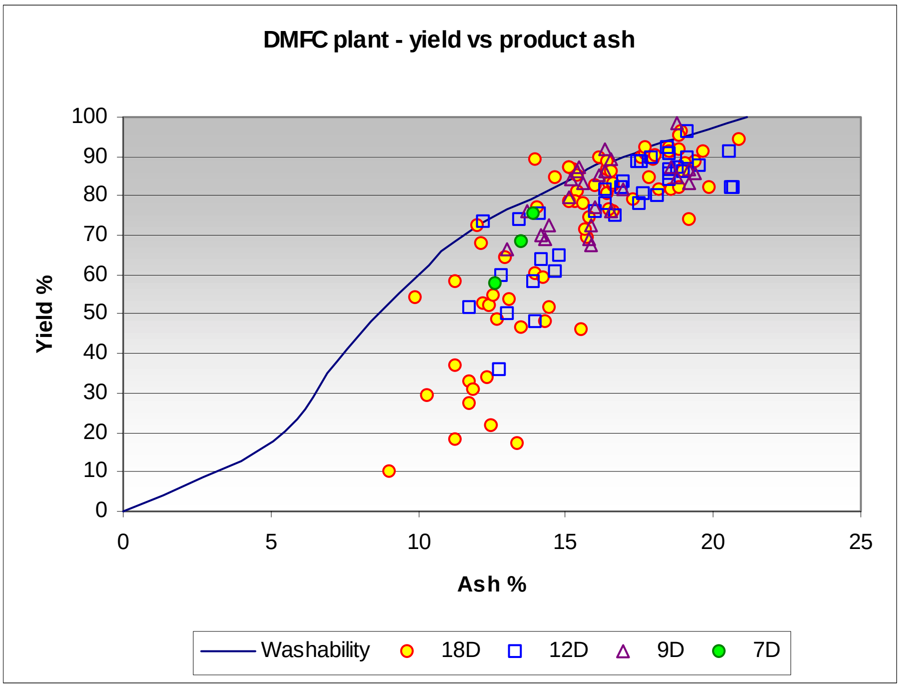

Figure 2: Ash content and yield of product coal produced

2.5 Density of separation

The product ash values obtained from the plant were initially very high, in the order of 20% ash. It appeared that the plant was separating the coal at a high cut-point density. This was confirmed by the first efficiency test, conducted on 29 November. At the time, the circulating medium density was being controlled at 1,45. The resulting cut-point density obtained was 2,14.

In order to produce a product containing 28 MJ/kg (approximately 13,3% ash), it was necessary to reduce the circulating medium's relative density to 1,25. At this circulating medium density, the effective cut-point density is still around 1,83 as found from a second efficiency test, conducted on 30 January 2002.

It is important to lower the cut-point density, especially when processing fine coal from the No. 4 Seam. This coal would need to be processed at a relative density of about 1,60.

The cut-point density can be lowered by using finer magnetite and lower cyclone feed pressures, and by modifying the cyclone dimensions.

The relative densities of the cyclone feed, overflow and underflow streams also indicate relatively large differentials (defined here as the difference between the underflow and overflow densities).

The table below shows some of the initial values recorded.

Table 2: Cyclone feed, overflow and underflow density measurements on 16 November 2001

Circulating medium RD	1,47	1,51	1,48	1,48
Primary cyclone feed RD	1,51	1,52	1,52	1,52
Primary cyclone overflow RD	1,42	1,46	1,45	1,42
Primary cyclone underflow RD	1,75	1,77	1,77	1,77
Floats cyclone feed RD	1,44	1,49	1,47	1,44
Floats cyclone overflow RD	1,41	1,44	1,42	1,40
Floats cyclone underflow RD	1,86	1,90	1,84	1,86
Sinks cyclone feed RD	1,57	1,60	1,57	1,57
Sinks cyclone overflow RD	1,39	1,43	1,42	1,38
Sinks cyclone underflow RD	1,83	1,82	1,85	1,83

It became apparent that the interrelation between the three dense-medium cyclones is quite complex. Normally, in dense-medium cyclone operation, the only “differential” of concern is the difference between the circulating medium density and the cut-point density achieved.

In the Coaltech plant, three different forms of “differential” are encountered. These are:

a) The difference between the feed, underflow and overflow densities in each of the three cyclones. This also relates to the density of separation achieved in each of the three individual cyclones.
b) The difference between the circulating medium density and the effective overall cut-point density of the three cyclones combined.
c) The difference between the densities of the medium pumped to each of the three cyclones.

The differential mentioned in a) can be reduced by using finer magnetite, by lowering the feed pressure to the cyclone and by increasing the diameter of the spigot in relation to the diameter of the vortex finder.

The difference between the circulating medium density and the overall density of separation is not the same as in conventional cyclone operation. In the latter case, the cyclone is fed with circulating medium (only) mixed with the coal feed.

In the case of the Coaltech plant, each of the three cyclones is fed with the overflow (floats cyclone) or underflow (sinks cyclone) or both the overflow and underflow (primary cyclone) from another cyclone. Circulating medium is added to the various streams to balance the flows but the proportion of this medium is relatively small in comparison with the other streams.

The circulating medium is the only stream whose density can be controlled directly. The densities of the other streams, such as the feed medium pumped to each of the three cyclones, differ from that of the circulating medium. The density of each of these feed streams depends on the density of the flow from which it originates.

To illustrate this point, consider again some of the data given in Table 2. One can see that at a circulating medium density of 1,47, the feed to the primary cyclone will be 1,51, the feed to the floats cyclone will be 1,44 and the feed to the sinks cyclone will be 1,57.

The difference between the feed densities of the three cyclones constitutes the differential mentioned above in c). If the difference in the cut-point densities of the three cyclones becomes large, a large recirculating load will build up in the circuit. This is detrimental to the operation of the plant since the cyclones could easily become overloaded.

It would therefore be ideal if the three cyclones could be fed at about the same density. From the density values given in Table 2, one can see that this is not presently the case.

2.6 Magnetite size consist

Magnetite is obtained for the test plant by bleeding some of the overflow medium from the main Koornfontein plant’s 610 mm dense-medium cyclones to the circulating medium tank in the test plant. It was anticipated that this magnetite, having been subjected to size classification in the 610 mm cyclones, would be fine enough for the test plant.

It would, however, appear that the magnetite is not fine enough. A sample of the magnetite was subjected to screening analysis and the results obtained are shown in Table 3. As can be seen from Table 3, only 65% of the magnetite was finer than 45 micron. The ideal is for 95% of the magnetite to be finer than 45 micron.

Table 3: Size consist of initial magnetite used

Screen size (micron)	*% Retained*	*Cumulative % retained*
+150	0,2	0,2
-150+106	0,4	0,6
-106+75	4,0	4,6
-75+45	30,4	35,0
-45+25	27,9	62,9
-25	37,1	100,0

It was therefore decided to empty the medium circuit and refill it with fresh, “superfine” magnetite.

Five tons of superfine magnetite was purchased from Martin & Robson (M&R) and this magnetite was introduced into the circuit on 21 January 2002. The magnetite did not make a dramatic difference to the differentials measured. This was probably because the magnetite was not as fine as expected. Samples of the magnetite were analysed and the size consist obtained is shown in Table 4.

Table 4: Size consist of M&R magnetite

Screen size (micron)	*% Retained*	*Cumulative % retained*
+150	0,1	0,1
-150+106	0,4	0,5
-106+75	3,6	4,1
-75+45	13,9	18,0
-45+25	13,6	31,6
-25	68,4	100,0

This magnetite was 82% finer than 45 micron.

A third batch of magnetite, donated for testing by Mr. Frank van Heerden of Idwala, was introduced into the circuit on 4 March 2002. This magnetite proved to be “superfine” as shown by the size analysis in Table 5.

Table 5: Size consist of Idwala magnetite

Screen size (micron)	*% Retained*	*Cumulative % retained*
+150	0,0	0,0
-150+106	0,02	0,02
-106+75	0,22	0,25
-75+63	0,63	0,87
-63+45	6,69	7,56
-45+25	28,76	36,32
-25	63,68	100,0

This magnetite is 92,4% finer than 45 micron and 63,7% finer than 25 micron.

The relative densities of the cyclone feed, overflow and underflow, as measured after the superfine magnetite had been introduced into the circuit, are shown in Table 6:

Table 6: Relative densities of cyclone feed, overflow and underflow on 6 March 2002

Circulating medium	1,20	1,25	1,30	1,35	1,40	1,45
Primary cyclone feed	1,21	1,26	1,28	1,40	1,42	1,50
Primary cyclone overflow	1,13	1,18	1,20	1,31	1,35	1,41
Primary cyclone underflow	1,54	1,61	1,65	1,68	1,71	1,73
Differential (underflow-overflow)	0,41	0,43	0,45	0,37	0,36	0,32
Floats cyclone feed	1,16	1,18	1,21	1,30	1,39	1,43
Floats cyclone overflow	1,10	1,09	1,15	1,22	1,30	1,36
Floats cyclone underflow	1,51	1,57	1,62	1,68	1,69	1,73
Differential (underflow-overflow)	0,41	0,48	0,47	0,46	0,39	0,37
Sinks cyclone feed	1,32	1,37	1,41	1,50	1,52	1,57
Sinks cyclone overflow	1,13	1,1	1,13	1,26	1,29	1,34
Sinks cyclone underflow	1,65	1,76	1,81	1,85	1,87	1,88
Differential (underflow-overflow)	0,52	0,66	0,68	0,59	0,58	0,54

As can be seen from Table 6, reasonably low differentials are obtained. It is also evident from the data presented that the density of the three cyclone feed streams differs quite substantially.

2.7 Cyclone feed pressure

The initial feed pressure to the cyclones was 9D. By changing the pulley sizes, and hence the speed of the feed pumps, the pressure can be changed. The pressure was changed to 12D and to 18D during test work. Some effect on the cyclone density differentials was noted, but no significant effect on product quality could be detected. The data presented in Figure 2 serve to illustrate the latter point.

The influence of cyclone feed pressure is an aspect of the test plant that still needs further investigation.

2.8 Cyclone geometry

Increasing the size of the spigot on a cyclone usually results in a lowering of the relative density of the cyclone underflow and hence a lowering of the differential between the overflow and underflow densities.

Since high differentials were measured on all three cyclones (Table 2), it was decided to change the spigot sizes in an attempt to lower the differentials. The primary cyclone spigot was increased from 120 mm to 145 mm and the size of the floats cyclone spigot was increased from 100 mm to 120 mm. The sinks cyclone spigot was left as it was at 85 mm.

As expected, the change did result in a slight lowering of the differentials. It was, however, also found that the difference between the feed densities of the three sets of cyclones increased as a result. It seems that the increase in the volume of underflow from the primary cyclone raised the relative density of the sinks cyclone feed. The increase in the volume of the underflow from the floats cyclone caused an increase in the relative density of the medium being fed to the primary cyclone.

This again emphasises the fact that the complex interaction between the three cyclones needs to be taken into account when making any changes within the circuit.

The following two graphs, Figures 3 and 4, illustrate the effect on cyclone feed densities resulting from an increase in the spigot sizes of the primary and floats cyclones.

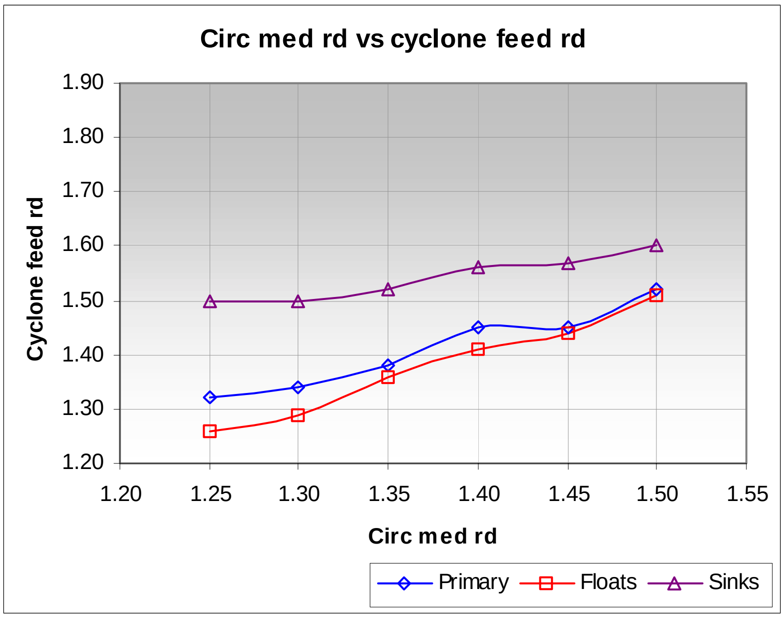

Figure 3: Cyclone feed densities before changing spigot sizes

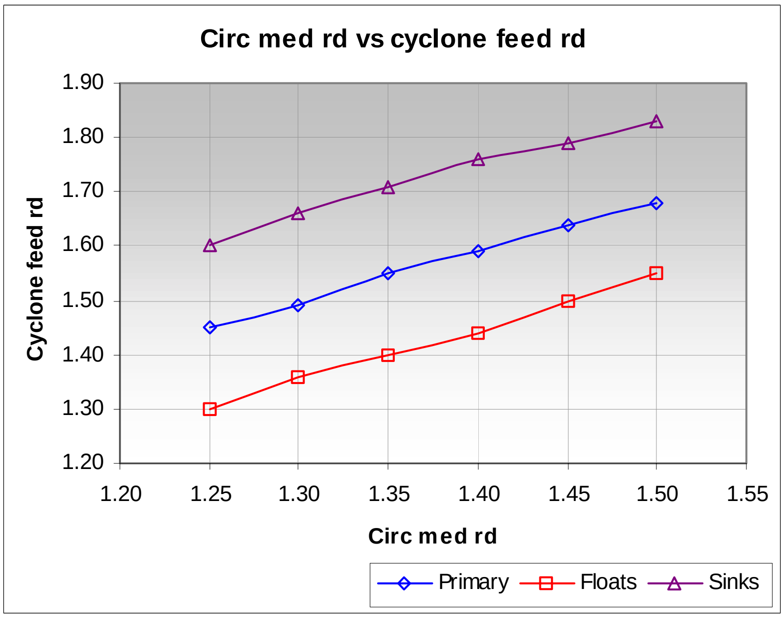

Figure 4: Cyclone feed densities after changing spigot sizes

2.9 Efficiency tests conducted

Two separate efficiency tests have been conducted on the plant to date. The first test was conducted on 30 November 2001 and the second test on 30 January 2002.

The samples taken during the first test were sent to Khanya laboratories for analysis and the samples for the second test were analysed by Coal and Mineral Technologies (CMT).

The results obtained from the two tests are summarised in the following table.

Table 7: Summary of efficiency test results

Efficiency Test Results: **Coaltech 2020 Test Plant**		
	Test 1: **30 Nov 2001**	**Test 2:** **30 Jan 2002**
Feed % Ash	**21,2**	**21,5**
Product % Ash	**17,8**	**15,6**
Discard % Ash	**55,9**	**58,2**
Product Yield	**91,2**	**86,1**
D50	**2,14**	**1,83**
EPM	**0,051**	**0,066**
Organic Efficiency	**98,9**	**98,5**
Sink in Float	**1,06**	**1,64**
Float in Sink	**3,70**	**2,37**
Total Misplaced	**4,76**	**4,01**

The partition curves obtained are shown below in Figures 5 and 6.

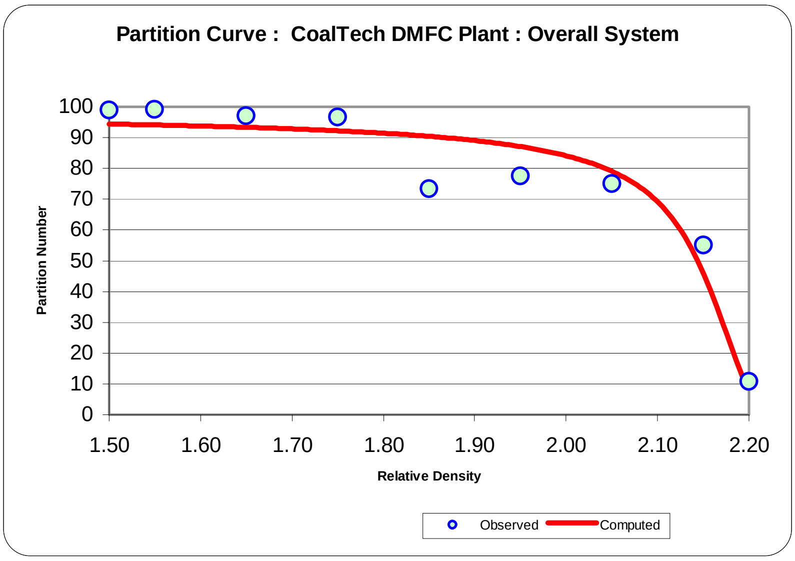

Figure 5: Partition curve for Test 1

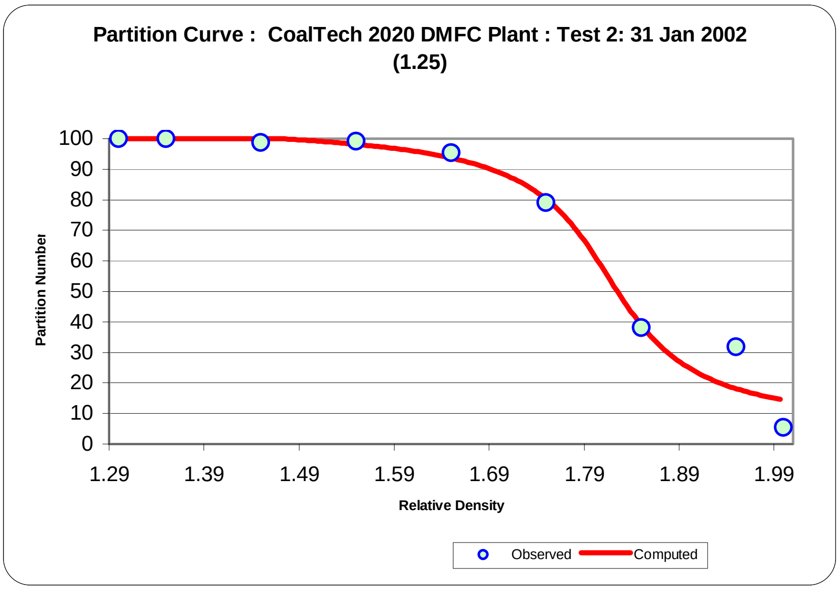

Figure 6: Partition curve for Test 2

From the results shown in Table 7, it is evident that the cut-point density was very high in both the tests.

The Epm values obtained are much better than those obtainable from spirals. The organic efficiency and the amount of misplaced material are also quite good.

2.10 Magnetite consumption

One of the initial concerns about the plant was that magnetite consumption would be high. To date, the consumption of magnetite has been reasonably low and the loss measured amounts to approximately 1,50 kg/ton.

The very good performance of the multi-pole, counter-rotation magnetic separators supplied by Magnapower and Malvern Engineering is probably the main reason for the low magnetite consumption.

The efficiency of the magnetic separators was measured on 30 November 2001 and found to be in excess of 99,9%.

Samples of the magnetite lost in the magnetic separator underflows were collected by using a magna-chute. These samples were sent to the National Metrology Laboratory at the CSIR for analysis by electron microscope.

The results of the electron microscope analysis showed that the magnetite lost from the circuit is extremely fine. The average particle size of the magnetite lost from the product magnetic separator is 4,5 micron and the corresponding figure for the magnetite lost via the discard magnetic separator is 3,8 micron.

The size distribution of the magnetite lost is shown in Figures 7 and 8 below.

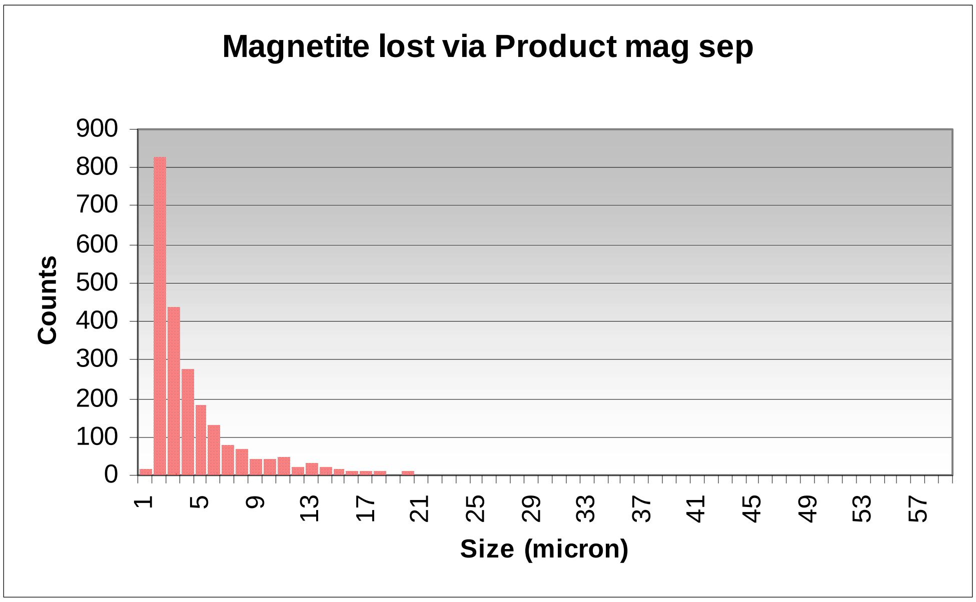

Figure 7: Size distribution of magnetite lost via product magnetic separator

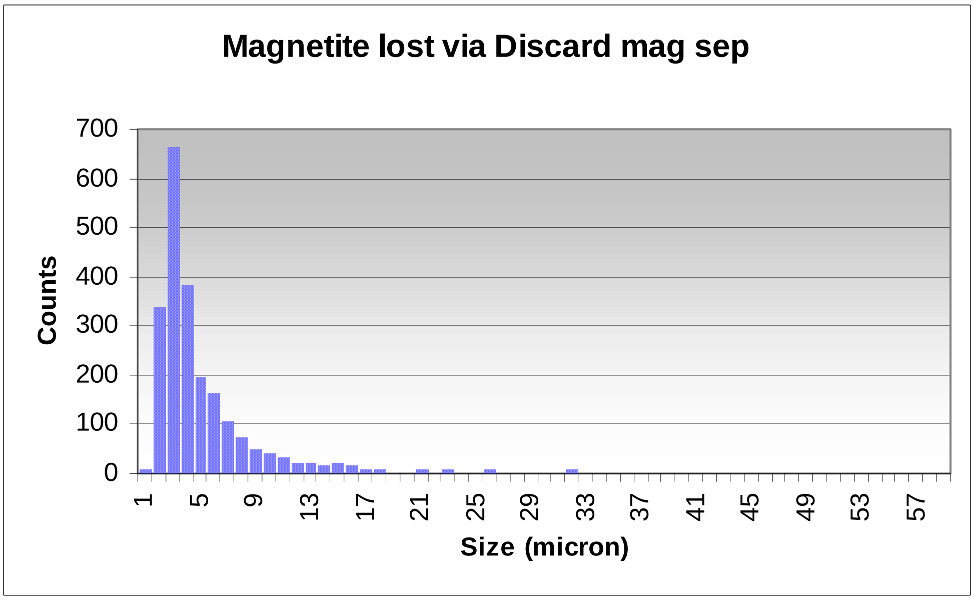

Figure 8: Size distribution of magnetite lost via discard magnetic separator

Previous dense-medium fine coal plants, such as the one at Homer City, reported a gradual coarsening of the medium in circuit due to the preferential loss of superfine magnetite from the circuit. The results presented above would seem to confirm that this could also be the case in the Coaltech plant. Not enough information is available yet to confirm this, but it is very important to conduct more work in this regard.

It may be necessary in future plants to consider using a Malvern Magmiser to recover the superfine magnetite currently being lost from the circuit.

2.11 Operating hours

Up to the present, the plant has not been operational for extended periods and has been operated only on single, day shifts.

It is planned to run the plant for extended periods to ensure that it can operate as a production unit.

3 CONCLUSIONS AND RECOMMENDATIONS

The plant has been successfully commissioned and the first results obtained are very encouraging.

The following issues still need to be addressed:

- The feed tonnage to the plant needs to be increased to the design 25 t/h.
- The density of separation needs to be lowered to 1,60 at least.
- The plant must be run for extended periods to prove that it can operate as a production unit.
- The magnetite in circuit must be monitored to ascertain whether or not a coarsening of the medium is occurring due to the preferential loss of superfine magnetite.
- The effect of higher plant feed tonnages on magnetite consumption needs to be monitored.
- The influence of cyclone feed pressure needs to be more fully investigated.
- The influence of the magnetite size consist on the separation efficiency requires further quantification.
- Measurement and control of the relative density of the feed to the individual cyclones need to be considered. This aspect will be very important in controlling the amount of coal recirculated within the system.

APPENDIX A: SCOPE OF WORK FOR PROPOSED DENSE-MEDIUM CYCLONE PILOT PLANT

The purpose of the proposed dense medium cyclone pilot plant is to demonstrate to the coal industry that fine coal (minus 1 mm plus 0,15 mm) can be beneficiated to the required quality efficiently and economically through the use of dense-medium cyclones.

In order to demonstrate the process, a small, minimum-cost pilot plant is required to be designed, constructed and operated at one of the existing collieries.

A flow sheet for the plant is shown in Figure A.

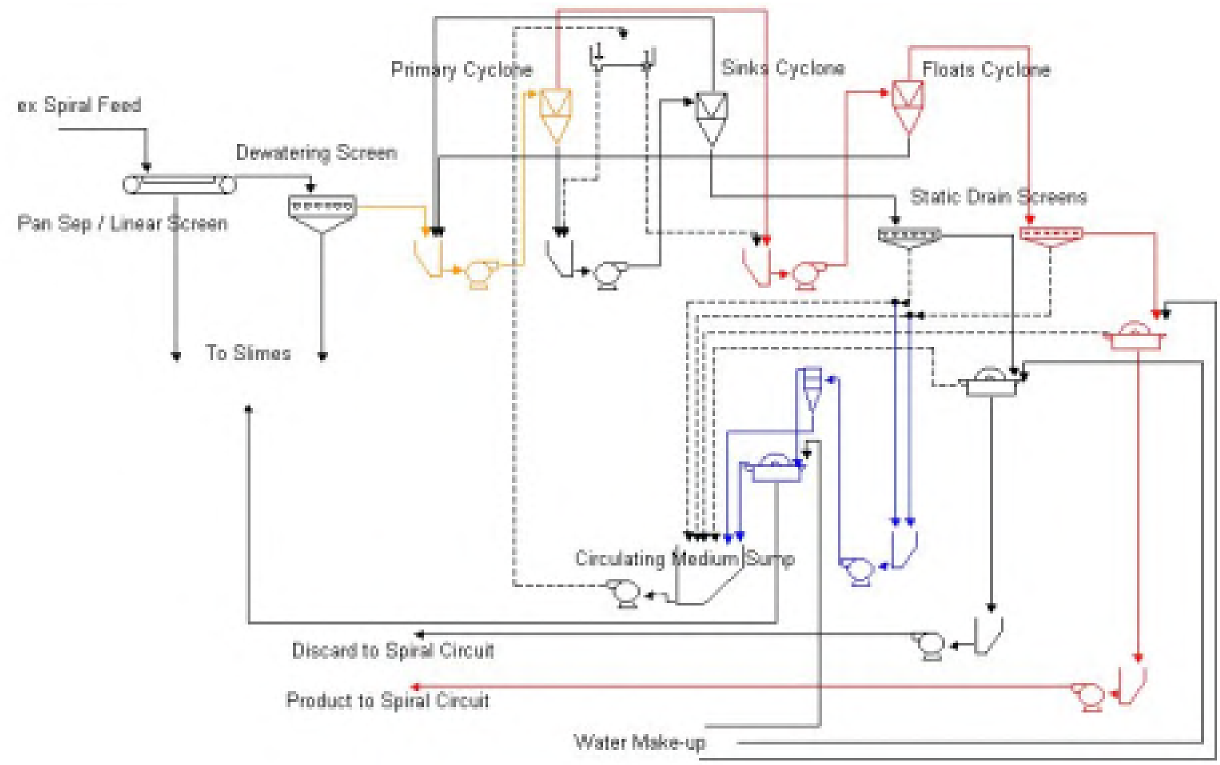

Figure A: Concept flow sheet for dense-medium pilot plant

The plant receives approximately 20 to 25 t/h (dry solids) feed as a de-sliming cyclone underflow. Alternatively, the feed may be supplied as a spiral feed after dilution of the de-sliming cyclone underflow.

The feed, which still contains some “slimes” (material finer than 150 micron in size), is de-slimed using a device such as a Linear Screen or Pansep.

The de-slimed feed is dewatered, using a conventional dewatering screen, and mixed with circulating medium in a feed sump. This coal/medium mixture is pumped to a primary 400 mm dense-medium cyclone.

The overflow from the primary cyclone reports to a second feed sump. A small amount of medium, fed from a splitter box, is added to the feed sump to make up the coal/medium volume to the required amount for pumping to a second-stage 400 mm dense-medium cyclone.

The overflow of the secondary (Floats) cyclone constitutes the product coal and is gravitated to a static drain screen. The screen overflow is diluted with clarified water and sent to a magnetic separator for recovery of the medium. The recovered medium is pumped, or gravitated, to a circulating medium sump.

The magnetic separator underflow, representing the final product (in diluted form), is pumped back either to the existing spiral product dewatering circuit or to the existing spiral feed stream.

The secondary dense-medium cyclone underflow is recirculated back to the primary dense-medium cyclone feed sump.

The underflow of the primary dense-medium cyclone reports to a third feed sump. Medium is added from a splitter box to this sump so as to make up the volume of the coal/medium mixture to that required for pumping to a third 400 mm dense-medium cyclone.

The overflow from this third (Sinks) dense-medium cyclone is recirculated back to the primary dense-medium feed sump.

The underflow from the Sinks cyclone is gravitated to a static drain screen. The screen overflow is diluted with clarified water and sent to a magnetic separator for recovery of the medium. The recovered medium is pumped, or gravitated, to a circulating medium sump.

The magnetic separator underflow, representing the final reject, is pumped back either to the existing spiral reject dewatering circuit or to the existing spiral feed stream.

The medium drained from both the product and reject static drain screens reports to a sump from where it is pumped to a magnetite-cleaning cyclone. The underflow from this cyclone reports to the circulating medium sump.

The overflow from this cyclone is fed to a third magnetic separator for cleaning and recovery of the magnetite contained in the overflow. The magnetic separator concentrate is gravitated to the circulating medium sump.

The magnetic separator underflow is pumped to the existing thickener feed system.

Make-up medium is supplied from the existing dense-medium cyclone circuits. It is envisaged that the supply will be taken from a dense-medium cyclone overflow sieve bend underflow so as to ensure a magnetite with a finer size distribution.

The flow process described may not ultimately prove to be the final circuit decided on and hence it is very likely that changes may be affected in the flow sheet.

The plant design should therefore be flexible enough to accommodate possible changes to the circuit.

It is possible that the plant, after initial testing and proving of the concept at one location, may be dismantled and moved to a second and perhaps even a third site for further testing.

Sampling of the plant products will be a very important part of the test work. Although it is anticipated that most of the samples will be “grab samples”, at least initially, it is still important to make allowance for access to the various streams so as to facilitate safe sampling.

Scheduling of the project is such that the plant needs to be completed by December 2001 at the very latest.

Simplified Flow Diagram

CoalTech 2020 Dense Medium Fine Coal Plant (Configuration as at SWC)