COALTECH

Dry Dense Medium processing of raw coal – progress report

GJ de Korte

CSIR

March 2016

Report CSIR/NRE/MMR/ER/2016/0010/B

Executive Overview

Dry Dense Medium (DDM) processing of raw coal is a process that employs a fluidized bed of dry solids to simulate a dense medium. The process holds much promise for the South African coal industry since it offers the potential to dry-process raw coal with very good separation efficiency, therefore allowing mines to process difficult raw coals to exacting quality specifications.

There are, however, a number of limitations and difficulties associated with DDM and the most important of these is the requirement that the raw coal feed to the process has to be dry – thus making it necessary to thermally dry the feed in most cases. In addition, the process is restricted to the processing of coarse coal and it will also be necessary to find a suitable source of magnetite to serve as the dense medium for the process.

Contents

1. Introduction

In the recent past, Coaltech has conducted research aimed at finding effective methods to dry-process raw coal – mainly with the specific aim of upgrading the coal to thermal coal specification.

Dry processing methods investigated to date include the FGX (Fuhe Gan fa Xuan mei) compound dry coal washer as well as X-Ray sorting. Both of these technologies were proven capable of de-stoning raw coal and both technologies have found limited application in the South African coal industry. There are, however, limitations to both these dry processing methods - in the case of the FGX it is mainly the poor separation efficiency and in the case of the X-Ray sorter, it is primarily the size range of coal that can be effectively processed.

The FGX is capable of processing raw coal in the size range 80 mm down to 0 mm but it typically has an EPM value of around 0.20 to 0.30 and a cut-point density of 1.80 and higher. This makes the unit unsuited to processing raw coals with high near-dense content and in many instances it was found that the FGX could not produce a product quality of 30% ash which is required for the current thermal coal market when processing some local raw coals. Although the raw coal feed to a FGX can contain coal down to 0 mm, it was found that the unit is not able to effectively upgrade coal smaller than about 6 mm. It is therefore better to remove the minus 6 mm raw coal from the feed as this increases the effective capacity of the unit and reduces the operational problems caused by fine, damp coal.

The X-Ray sorter is best applied to sorting raw coal sized between about 50 mm and 150 mm. This restricts the application of these units to pre-processing run of mine coal.

Although there are definite application areas for both the FGX and the X-Ray sorter, there is still a requirement for an efficient dry process capable of upgrading a wider size range of raw coal to produce thermal coal within specification. Dry dense medium (DDM) is a process that can potentially fulfil this requirement and was proven in China to be able to process 50 x 12 mm coal effectively at low relative densities (1.50) and with good EPM values (0.05). For this reason, Coaltech decided to investigate the DDM process in more depth.

2. Dry dense Medium Separation

Dry dense medium separation is a process in which a bed of medium (sand or other suitable materials such as magnetite) is fluidised by an upward flowing stream of air, distributed evenly across the bed. The bed, once fluidised, acts like a dense liquid and light particles (coal) can float on the fluidised bed whilst heavier particles (shale) will sink. By controlling the velocity of the upward air flow as well as the type and density of the medium used, an effective separation between coal and shale is possible.

As with many other current technologies, the DDM process is not entirely new and was in fact patented in the United States as long ago as 1926 by Thomas Fraser and H. F. Yancey (Ref 1). At the time they proved the process on a laboratory scale but no further development was carried out.

It was only in the early 2000's that the process received renewed attention and research was conducted in China (Ref 2), Japan (Ref 3), the Netherlands (Ref 4) and India (Ref 5). Coaltech also sponsored some research conducted at the University of Kwa-Zulu Natal during 2009 (Ref 6) and at the University of the Witwatersrand in 2011 (Ref 7).

At present, the process is only used commercially in China, and still on a limited scale with a single 50 tonne per hour plant in operation at Shenhua (Ref 8). A photograph of the plant at Shenhua is shown in Figure 1. Another 50 tonne per hour plant was previously in operation at Zhangjiakou in China but this plant has since been dismantled because the contract between the service provider and the mine has been completed.

Figure 1: Dry Dense Medium plant in operation at Shenhua, China.

3. Dry Dense Medium plant performance

The DDM plant at Shenhua has been in successful operation for more than a year now and the performance of the plant has been assessed by the China Mining University. The plant was found to cut at a relative density of between 1.40 and 1.50 with a typical EPM value of 0.055. The partition curve determined during the efficiency determination conducted by the university is shown in Figure 2.

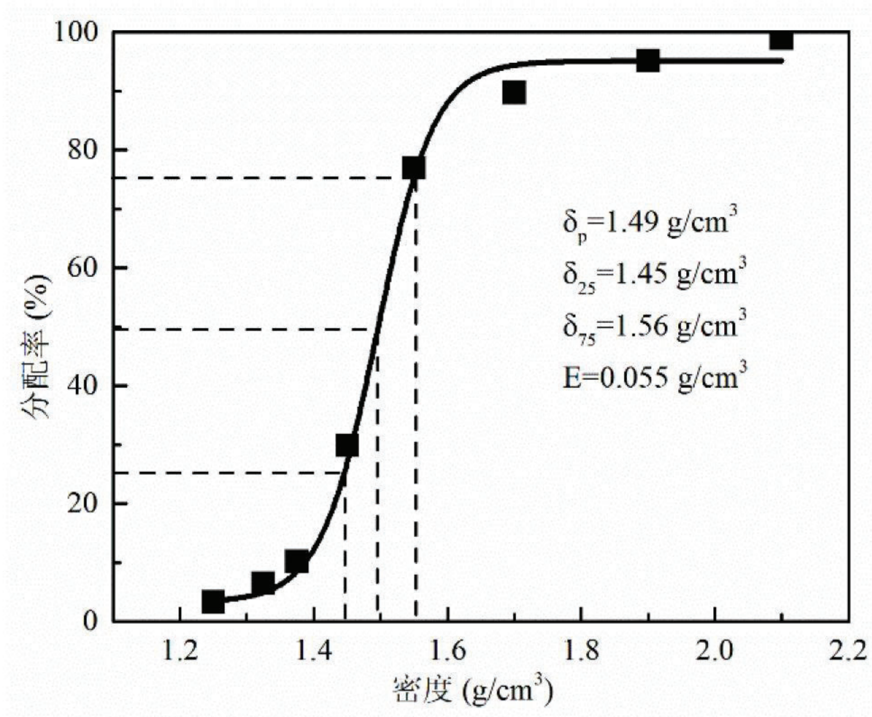

Figure 2: Partition curve - Dry Dense Medium plant at Shenhua

Exxaro sent some samples of raw coal to China during 2013 for tests to be conducted on the DDM plant which was in operation at Zhangjiakou at the time. A total of eight tests, supervised by Exxaro personnel, were carried out on the raw coal shipped to China. The first four tests (1 to 4) were conducted on raw coal from one source and tests 5 to 8 on raw coal from a second source. The average size analyses of the two batches of raw coal are shown in Table 1 and the average results obtained during the two test series are summarised in Table 2. The partition curves determined from samples taken during the test runs are shown in Figures 3 and 4.

Table 1: Size analyses of Exxaro raw coal

Screen size (mm)			Average feed (Tests 1 - 4)		Average feed (Tests 5 - 8)	
			Fractional %	Cumulative %	Fractional %	Cumulative %
	+	80.0	0.0	0.0	0.0	0.0
80.0	+	50.0	3.5	3.5	2.3	2.3
50.0	+	40.0	12.5	16.0	9.4	11.8
40.0	+	25.0	27.3	43.3	25.8	37.5
25.0	+	20.0	8.9	52.2	8.7	46.3
20.0	+	12.5	21.7	73.9	21.3	67.6
12.5	+	8.0	12.3	86.1	14.0	81.5
8.0	+	6.0	6.4	92.5	8.4	89.9
6.0	+	4.0	3.6	96.1	5.0	94.9
4.0	+	2.0	1.6	97.7	2.1	97.0
2.0	+	1.0	1.3	99.0	1.6	98.6
1.0	+	0.0	1.1	100.1	1.4	100.0

Table 2: Summary of DDM test results

Parameter	Test 1 - 4	Test 5 - 8
Feed % Ash	63.1	48.6
Product % Ash	19.9	20.1
Discard % Ash	68.9	69.6
Product Yield %	11.80	42.42
D50 cut-point density	1.458	1.564
EPM	0.0437	0.0456
Organic Efficiency %	60.1	92.4
Sink in float %	3.73	1.25
Float in sink %	2.93	4.47
Total misplaced %	6.66	5.72
Near-dense material	17.1	10.8

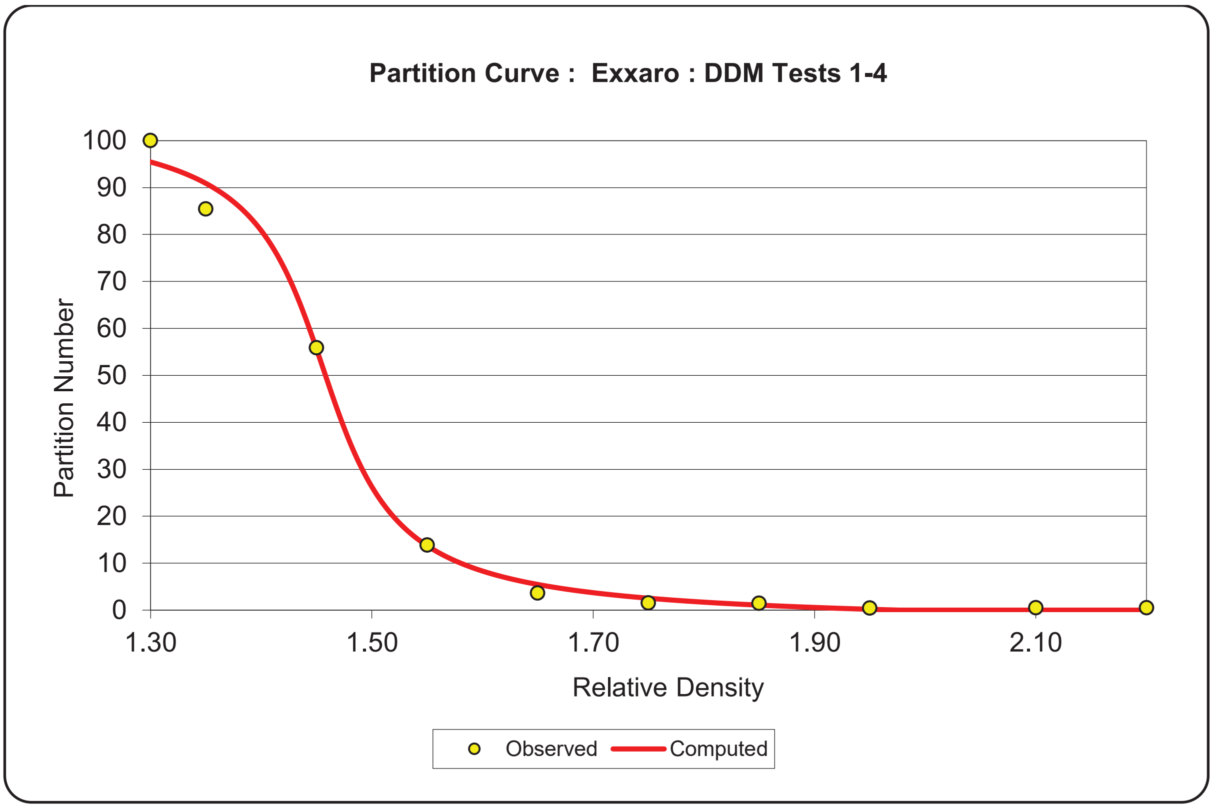

Figure 3: Partition curve – Exxaro Tests 1-4

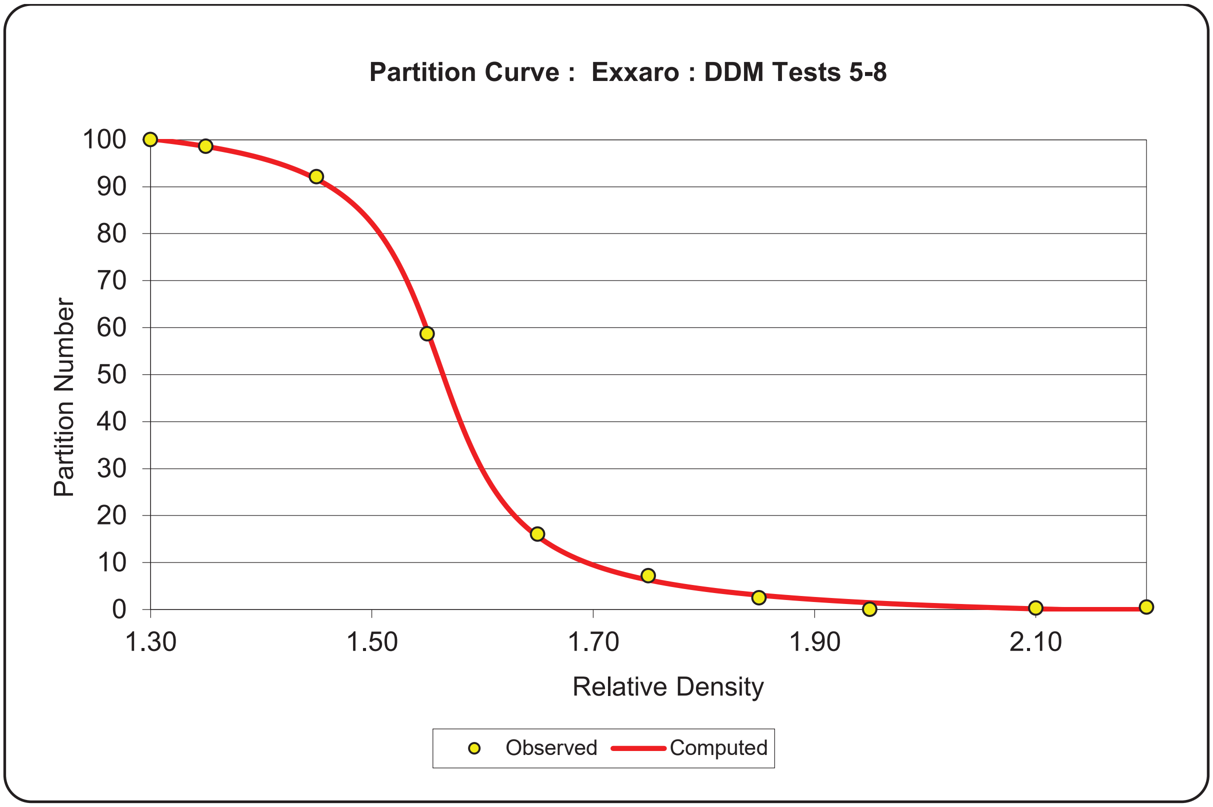

Figure 4: Partition curve – Exxaro Tests 5-8

It is evident from the results obtained during the Exxaro tests at Zhangjiakou as well as the performance test of the plant in operation at Shenhua that DDM separation can be very effective and efficient. The separation is almost as sharp as that obtainable from conventional wet dense medium processes and far superior to that of the FGX. If applied in South Africa to produce thermal coal, the process should aid both small and large coal producers to maximise recovery and produce thermal coal within strict specification levels. It therefore can potentially provide a processing technology that includes the advantages of dry processing whilst at the same time also allowing good separation efficiency as well as control over the quality of the product coal.

Despite the clear advantages offered by the DDM process, it has not been implemented widely across the world and this point to the fact that there are a number of complicating factors holding back widespread adoption of the technology. These factors are discussed next.

4. Some important issues regarding the DDM process

The most important issues to consider are:

- Size range of feed
- Moisture content of feed and fluidisation air
- Type, source and size analysis of medium
- Control of bed density

- Range of cut-point densities possible
- Recovery of magnetite
- Capital and operating costs
- Dust

a. Size range of feed

The DDM process is currently only applied to coal coarser than approximately 12 mm. This limitation is the result of the nature of a fluidised bed of dry material such as sand or magnetite. A degree of circulation occurs within the fluidised bed and small particles (below say 12 mm) will be drawn into the circulating streams and 'back-mixed' – hence the density separation of these particles in the bed is very poor.

A second reason for eliminating the finer fraction from the feed to a DDM plant is moisture. The finer size fraction of coal carries a high proportion of moisture with it and moisture content is a major negative factor in a DDM plant.

b. Moisture content of feed and fluidisation air

In the DDM process, coal is mixed with the medium in the fluidised bed to affect a density separation. After the separation process, the coal is subjected to screening to remove the medium from the coal. Under normal circumstances, and if the coal is completely dry, this is an easy operation since the coal is coarse (+ 12 mm) and the medium is fine (-1 mm). When the coal is damp or wet, however, the process becomes very difficult since the medium will adhere to the coal and will be lost from the process.

It may seem strange that a dry process requires thermal drying of the feed coal but in many cases, this will be needed to ensure that the coal entering the process is dry and has a surface moisture content of less than 3%. On average, run-of-mine coals in South Africa have surface moisture contents of around 5% to 6% as a result of the water used in the mining process – mainly to suppress dust. Therefore, drying of the feed will most likely be required if the process is employed in South Africa.

Screening of the feed to remove the minus 12 mm coal aids the drying process of the coarse coal somewhat. The air used to fluidise the medium also needs to be dry since damp fluidisation air can result in condensation of water in the fluidised bed which will cause a problem in medium recovery.

It should be noted that the DDM plant in China uses a thermal dryer to ensure that the plant feed is dry enough to limit magnetite losses. The dryer used in the plant is a 'SZ Series Mixed Flowing Vibrating drying system' which uses a multi-layer of vibrating screens to transfer the coal through the dryer. The coal is introduced into the top of the dryer and transported in a downward direction – passing from screen to screen. Hot air is blown upwards into the dryer and passes through the screens to remove moisture from the coal. A dust collection system is provided to contain dust. The dryer is shown in Figure 5.

Figure 5: SZ Series thermal coal dryer

Hot air for drying the coal is produced by a coal fired furnace. The air is initially heated to approximately 800℃ but the temperature of the air used for drying is about 240℃ due to cooling in the air distribution system between the furnace and the dryer.

Should Coaltech acquire a pilot DDM plant for testing in South Africa, the plant will not be equipped with a thermal dryer. It will be necessary to ensure that the coal used during tests is sufficiently dry and in this regard, the coal may have to be pre-screened and stockpiled for a few days to dry to the required moisture level.

c. Type, source and size analysis of medium

Although several different materials can serve as the medium for a fluidised bed, there are a number of requirements that will dictate whether or not a material is suited for use as a medium. A very important consideration for a medium is the size-consist of the material. Material that is very fine will be blown out of the bed whist material that is too coarse will not fluidise. There is an optimum size range for every specific material which depends on the relative density of the material. The specific particle size range and relative density of the medium will also influence the relative density of the fluidised bed and hence dictate the density at which coal will be separated in the bed.

Silica sand is a relatively inexpensive medium and can be applied to separate coal in a fluidised bed. Recovery of the sand by screening does not present any problems but cleaning of the medium does. During normal operation of a DDM plant, fine particles will be abraded from the coarse coal being processed and will gradually build up in the medium. Eventually, the fine coal in the medium will influence the properties and density of the medium. It is therefore required to continually withdraw a portion of the medium from the bed, remove the fine coal from it and return the cleaned medium to the bed. When magnetite is used as the medium, the medium can be cleaned with a magnetic separator. This cannot be done when the medium is silica sand or any other non-magnetic material. It is for this reason that magnetite is the favoured medium for the process.

In the plant in operation in China, magnetite is used as the medium but a certain proportion of fine coal is allowed to build up in the medium. This is found to stabilise the medium and it aids in controlling the density of the fluidised bed. The size analyses of the magnetite used in the plant at Shenhua is shown in Table 3.

Table 3: Size analysis of magnetite used at Shenhua

Screen size (micron)	Circulating medium	
	Fractional %	Cumulative %
+ 1000	4.7	4.7
- 1000 + 500	3.7	8.4
- 500 + 250	17.5	25.9
- 250 + 125	29.2	55.1
- 125 + 75	34.3	89.4
- 75 + 45	9.0	98.4
- 45 + 0	1.6	100.0

As can be seen from Table 3, the magnetite is much coarser than the magnetite normally used for wet dense medium processing. The magnetite currently supplied by Martin & Robson is obtained by classifying magnetite concentrated from the tailings of the copper plant at Palabora Mining Company (PMC). The un-classified PMC magnetite could potentially be used as a medium in the dry dense medium process but even this magnetite is finer than that shown in Table 3 as can be seen from the graph in Figure 6. Figure 6 also shows the size analysis of the medium grade magnetite currently in use at most SA coal processing plants.

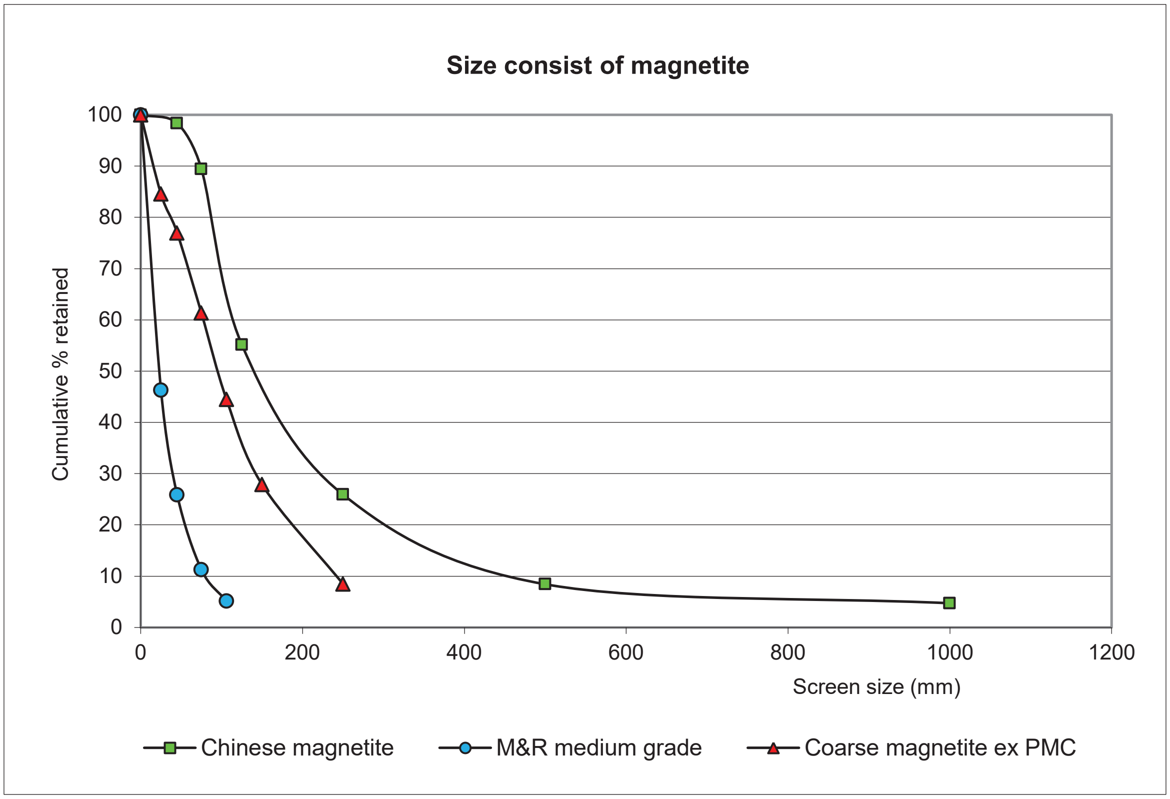

Figure 6: Comparison between Chinese and raw un-classified PMC magnetite

The supply of a suitable magnetite for use in the DDM process could therefore be an issue that will have to be addressed.

d. Control of bed density

The apparent relative density of a fluidised bed is a function of the density of the medium solids used as well as the degree of expansion of the medium bed by the fluidising air. When at rest, the bed density will be equal to the bulk density of the medium solids. Once fluidisation starts, the bed will expand and the increased volume of voids between the medium particles will result in a reduction in the relative density of the bed. The apparent relative density of the bed will thus be proportional to the degree of expansion provided by the fluidisation air. By measuring the pressure drop across the depth of the bed, a measure of the relative density of the bed can be derived and this can be used to control the relative density of the bed.

In order to keep the fluidised bed at a constant and controllable relative density, it will be required that the distribution of the fluidising air be evenly distributed over the area of the bed and that the composition and size consist of the medium remain constant. It is not known what the influence of the coal fed into the unit will be on the stability of the fluidised bed density but it is likely that it will exert an influence – hence it will be required to maintain the feed rate of raw coal to a DDM separator as constant as possible. It will furthermore be necessary to keep contamination of the medium with fine coal between pre-determined maximum and minimum levels. This will have to be done by withdrawing a calculated amount of the circulating from the bed and sending it to a magnetic separator for cleaning before returning it to the DDM vessel.

e. Range of cut-point densities possible

The suppliers of the DDM equipment claim that the unit can affect a separation between coal and shale over a wide density range and a cut-point density range of 1.30 to 2.20 is mentioned in literature (Ref 5).

Of main importance is that the unit can separate at low relative densities and this fact seems proven by the results obtained by Exxaro as well as the results from the Chinese plant at Shenhua.

f. Recovery of magnetite

Magnetite used in the fluidised bed can be lost via the product and discard streams by adhering to the coal or discard even after screening. As previously mentioned, the loss of magnetite will be made much more severe if the feed coal or fluidisation air contains moisture.

The circulating medium requires constant cleaning to remove non-magnetic material from the medium. A portion of the medium is therefore withdrawn from the circulating stream and routed to a magnetic separator for cleaning. Since magnetic separators are not 100% effective, some magnetite will be lost in the magnetic separator tailings. Losses of magnetite will be lowest when the medium and coal is completely dry but may increase significantly when the medium / coal mixture is damp.

Air is used to fluidize the bed and any fine material, which will include fine magnetite, will be blown from the bed and will report to the dust extraction system. Fine magnetite could potentially be lost in this way.

The plant at Shenhua reports magnetite losses of the order of 0.5 kg/ feed tonne which is in line with that of wet dense medium processing plants.

g. Operating costs

No detailed operating costs are available for DDM plants yet but, with the exception of thermal drying, should be comparable to that of conventional dense medium plants. As is always the case for coal projects, the business case for each specific application will be unique and the application of the DDM process will thus have to be evaluated for every proposed application.

h. Dust

Dry processing implies that coal dust will be present. The DDM plant in China is equipped with dust extraction equipment. Experience from the FGX, however, showed that some dust will still be present and it will be necessary to take precautions to protect the health of the plant operating staff.

i. DDM vessel configuration

There are a number of issues regarding the DDM process that is still not known. Some of these are listed below:

- Size and depth of the DDM vessel and bed
- Distribution system for air
- Specific air requirements
- Capacity – feed tonnes per hour per m2 of bed area

- Maximum floats and sinks capacity of the units
- The influence of near-dense material on the throughput capacity and separation efficiency

Some of the issues listed will be inherent in the DDM vessel and plant design but some of the issues will be coal-specific and will only be determined during testing of a DDM plant under local conditions.

5. Research projects

In order to improve understanding of the DDM process Coaltech is sponsoring research projects at South African universities aimed at addressing some of the issues listed above. The following projects are currently in progress at universities:

- Students at the University of Pretoria, under the guidance of Dr. Natasia Naude, will investigate the recovery of magnetite. In this regard, the loss of magnetite during screening of the product and discard coal will be investigated and the recovery of magnetite and the cleaning of medium with dry magnetic separation will be studied. The influence of moisture content on both the screening and magnetic separation processes will be quantified.

- The University of the Witwatersrand will investigate alternative medium solids suited to the DDM process. The project will include testing of differening medium solids as well as identification of the sources of the different medium solids identified. The project leader at the university is Dr. Samson Bada.

- The North West University will conduct a project aimed at finding a process suited to dry-upgrading of small and fine coal. The study will look at using DDM as well as possible alternative processes. The study leader at the university is Professor Quentin Campbell.

- Coaltech plans to acquire a 10 t/h pilot plant from China and to conduct practical, hands-on testing of the DDM process at a local colliery. At present, sources of funding for the plant is being addressed. Once the plant becomes available, a suitable coal mine, preferably a junior miner, will be identified where the plant will be installed for testing.

6. Conclusions

The DDM process is a very attractive option for dry processing the difficult South African raw coals in order to produce high-quality thermal coal products. It offers a dry process with very good separation efficiency and it is for this reason that Coaltech has decided to conduct research to further local knowledge of the process. There are, however, some significant issues that will require consideration with the most important ones being:

- The moisture content of the raw coal feed to the plant
- Properties and sourcing of medium

7. References

1. Fraser, T. and Yancey, H.F. Artificial Storm of Air-Sand Floats Coal on Its Upper Surface, Leaving Refuse to Sink. Coal Age. March 4, 1926. Pp 325 -327.

2. Luo Zhenfu and Chen Qingru. Dry beneficiation technology of coal with an air dense-medium fluidized bed. Int. J. Miner. Process. 63 Ž2001. 167–175.

3. Tanaka, Z., Oshitani,J. and Kubo, Y. Dry coal cleaning process with fluidized heavy media. XIV International Coal Preparation Congress and Exhibition, South African Institute of Mining and Metallurgy, 2002

4. Van HOUWELINGEN, J.A. and de JONG, T.P.R. Dry cleaning of coal: Review, Fundamentals and Opportunities. GEOLOGICA BELGICA (2004) 7/3-4: 335-343

5. Sahu A.K., Biswal S.K. and Parida A. Development of Air Dense Medium Fluidized Bed Technology for Dry Beneficiation of Coal – A Review. International Journal of Coal Preparation and Utilization, 29: 216–241, 2009.

6. Kretzschmar,S. Pocock, J. and Loveday, B. Dry Beneficiation of Coal Using an Air Dense-Medium Fluidised Separator. Coaltech website (www.coaltech.co.za) accessed on 2 Feb 2016.

7. Chikerema, P. Effects of particle size, shape and density on the performance of an air fluidized bed in dry coal beneficiation. MSc. Thesis, University of the Witwatersrand.2011.

8. ZHAO Yue-min and LI Gong-min. Industrial application of modularized dry coal beneficiation technology based on air dense medium fluidized bed. Private communication. FavorSea Africa Pty Ltd.