The Case for dry processing

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Introduction

New and novel technologies are developed and implemented in industries in response to specific needs and requirements. In the case of dry processing of coal, old technologies that were previously used and were abandoned in favour of more efficient processes are now again being re-implemented in response to a specific requirement – the scarcity of process water in South Africa as well as in other countries like China and India. In addition to the fact that dry processing does not require any water, it also offers some other advantages to the coal industry. Dry processing plants are in general simpler in design and therefore less expensive to build and operate, they do not yield wet products and since no water is required, no slurry arises during processing therefore vastly reducing the pollution potential of coal processing operations.

Unfortunately, dry processing also has a negative side – in particular the fact that these processes are less efficient than wet (dense medium) processes. This is the main reason why dense medium processing of coal became so popular during the middle of the previous century and dry processing was phased out. The unavailability of water for wet processing now makes it necessary to re-consider dry processing technologies.

In addition to not requiring water, the simplicity and low cost of dry processing makes it a very attractive option, especially for smaller coal producers. Implementation of dry processing should, however, be carefully evaluated on a per-case basis since the low separation efficiency of the process can potentially off-set the advantage of low cost. It should also be taken into account that current dry processing techniques are not able to effectively beneficiate all South African coals.

Through the Coaltech collaborative research program, a number of studies aimed at evaluating the available dry processing and dry screening technologies were completed in recent years. These studies have provided valuable know-how and assisted the local coal industry to implement some of these dry processing technologies.

Some history

Dry processing of coal was used quite extensively in the first part of the 20th century – especially in the United States. The use of dry processing declined after the 1960’s as a result of mechanised mining methods which resulted in more contaminated and also in wetter coal since water is used in the mining process to control dust. It was also in the early 1960’s that dense medium processing of coal became popular and since this process was so much more efficient than dry processing, it became the mainstay in the coal industry.

The use of dry coal processing techniques recently re-emerged in China mainly as a result of the need to process coal in arid parts of that country. The Chinese revived and improved one of the dry processing technologies from the 1940’s (the FGX) and successfully implemented it to process some of their coals.

South Africa is also a water-scarce country and the need to implement dry processing technologies also exists in South Africa – especially in the Waterberg and Limpopo coalfields. The South African coal industry, through Coaltech, therefore decided to evaluate dry processing of local coal to ascertain whether these technologies could be gainfully employed in South Africa. To date, two dry processing techniques namely the FGX and X-ray sorting of coal have been evaluated and a preliminary evaluation of a third dry processing technology, the Allair Jig, was conducted in co-operation with IMS and Slater Coal Marketing.

FGX

The FGX (*Fuhe Ganfa Xuan mei = compound dry type coal washer*) is a dry coal separator based on the FMC (Food Machinery Corporation) shaking table developed in the US during the 1940's – Figure 1.

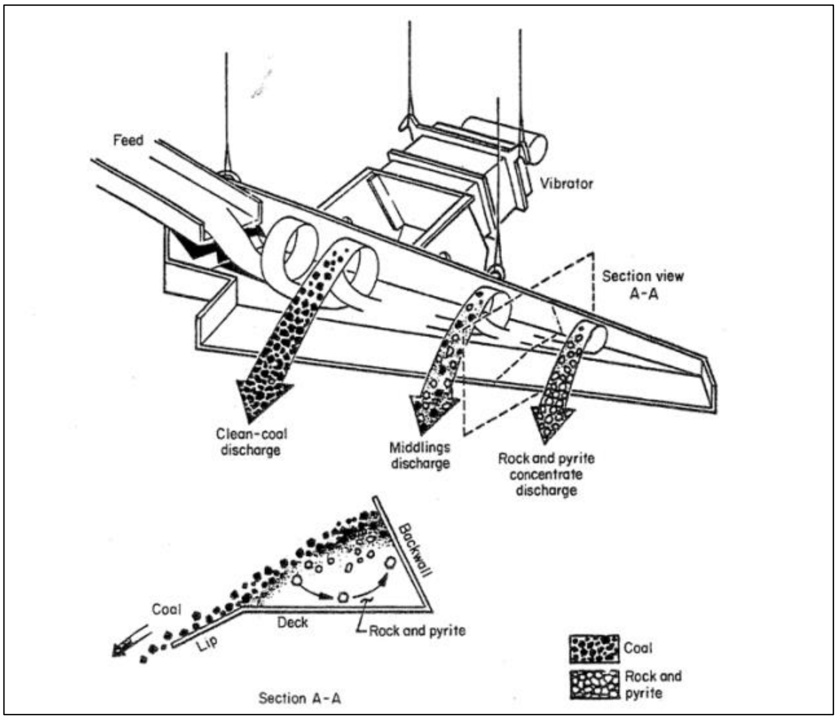

Figure 1: FMC separator (1940)

The FMC separator was able to separate coal from shale by applying vibration to a bed of coal on the table. The lighter coal stratified and moved to the top of the layer whist the heavier shale remained at the bottom of the layer. Since the table became narrower towards the end, the lighter coal was crowded off the table near the feed-end while the shale remained on the table longer.

The FGX improved on the FMC design by adding riffles to the deck of the table and also by providing a system to control dust. The table surface of the FGX is perforated to allow air, supplied from a fan, to flow upwards through the coal layer on the table to remove dust and transport it to a dust cyclone and bag filter arrangement.

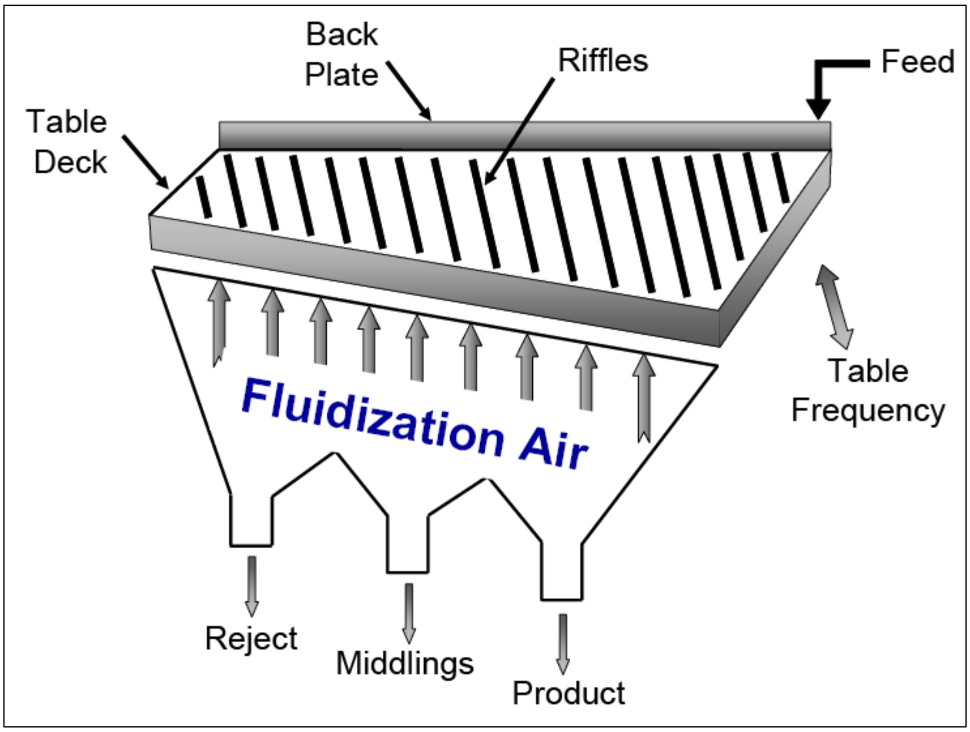

Figure 2: Diagrammatic view of FGX unit[1]

In the FGX, vibration is supplied to the deck in the direction shown in Figure 2. The back end of the table surface is bordered by a back-plate. The surface of the table is sloped slightly across the width of the table towards the open (discharge) side and can also be adjusted to have a slope along the length of the table.

Due to the vibration of the table, coal falling onto the table surface and coming into contact with the surface is subjected to a motion which causes the coal to move towards the back-plate (in the direction of the vibration). Heavy particles tend to move to the bottom of the layer of coal on the bed whilst lighter particles will migrate to the upper part of the layer. The heavier particles will therefore be in contact with the vibrating surface and will move towards the back-plate. Lighter particles will not be subjected to the motion imparted by the vibration to the same extent since they are not in direct contact with the table surface. These particles will be displaced towards the discharge lip of the table – mainly as a result of the slope of the deck and the displacement caused by new feed entering the unit. The fluidization air supplied through the deck surface by the fan aids movement of the coal on the table surface and assists small and light particles to move towards the upper parts of the coal layer on the deck.

The net result of the actions is a segregation of the coal into a fraction containing the lighter coal (and fine material) which is discharged towards the feed end of the unit and a fraction containing the heavier material which moves towards the back-plate of the unit and is discharged towards the end of the table. The coal towards the centre of the table constitutes a middling fraction. This is illustrated in Figure 3.

Figure 3: Product, discard and middling from FGX unit[1]

Exxaro purchased a 10 tonne per hour FGX unit and kindly made it available to Coaltech for evaluation. Extensive testing of the FGX was carried out at Exxaro's NBC Mine near Belfast. From the tests conducted at NBC it was concluded that the FGX typically separates at relative densities between approximately 1.80 and 2.00 and has an EPM value between about 0.20 and 0.30. It was also found that the minus 6 mm coal was not upgraded to any appreciable degree and reported with the product coal. When damp coal was processed in the FGX, the finer coal adhered to the table surface eventually blocking the apertures in the deck completely. This is seen illustrated in Figure 4.

Since the finer coal, especially the minus 6 mm size fraction, has a higher moisture content than the coarser coal, and is not effectively upgraded by the FGX, it was found expedient to remove the minus 6 mm size fraction from the feed to the FGX and send it directly to the product conveyor. This not only eliminated the blockage problem but also effectively increased the capacity of the plant by about 30%. The separation of the coarser coal was found to be un-affected by the removal of the fine coal.

Figure 4: FGX table deck blocked by damp fine coal

Xantium (now Genet Mineral Processing) also conducted independent tests on a pilot FGX unit and eventually constructed two full-scale FGX plants at Middelkraal Colliery and at Onverdacht Colliery. The FGX plant at Middelkraal, shown in Figure 5, was used to upgrade coal from the No. 2 Seam for use by Eskom. The plant has now closed down due to the depletion of the coal reserve but the FGX is being re-deployed at another colliery.

The FGX can be considered a ‘mature’ technology and further development is not considered likely.

Figure 5: FGX plant at Middelkraal

X-ray sorting

X-ray sorting of coal is a new technology and only became possible as a result of the development of low-cost, high-speed computing. It is a particle-by-particle separation technique in which a single layer thickness of coal particles is allowed to fall through a chute equipped with an x-ray source at the one side and an x-ray detector on the other. This arrangement allows each particle to be exposed to x-rays and the amount of x-ray energy absorbed by the particle to be measured by the detector. Particles with a higher density (shale and pyrite) will absorb more of the x-ray energy and will be seen as dark images by the detector. Lighter particles (coal) will reflect as a lighter image. These images are used by a computer software program to classify the particles into coal and shale based on the degree of x-ray absorption of each particle. The computer program can then control a jet of compressed air, via a series of nozzles, to 'blow' shale particles over a divider in the sorter onto the reject conveyor. Coal particles are allowed to fall unhindered into a separate compartment and then onto the product conveyor. When the sorter is processing say 100 tonnes of raw coal every hour, thousands of particles are measured, evaluated and if necessary ejected every minute.

Much of the development of the technology was jointly carried out by the Technical University of Delft in the Netherlands and the University of Aachen in Germany. The technology is relatively new and further development is possible.

Isambane Mining purchased a Commodas X-ray sorter for their own use and kindly allowed Coaltech to conduct test work with the unit at Arnot Colliery. From the tests carried out at Arnot, it was found that the X-ray sorter typically cuts at a relative density of between 1.80 and 2.10. Typical EPM values obtained fall between 0.15 and 0.20.

The unit works best with coarse coal, larger than about 30 mm and smaller than about 200 mm. It is possible to sort coal particles smaller than 30 mm but at a reduced feed rate.

Moisture content does not affect the separation of an X-ray sorter, provided the coal can be transported through the unit without blockages occurring. By removing the smaller coal from the feed to the sorter, even wet coal can be successfully sorted.

A photograph of an X-ray sorter in operation is shown in Figure 6.

Figure 6: X-ray sorter in operation

Allair Jig

The Allair jig is a modern version of the Stump jig (1932) and the Roberts & Schaefer Super Air-flow table (1942) which were popular dry processing units in the United States. Dry processing of coal in the United States peaked in 1965 when some 25 million tonnes of clean coal was produced annually by dry processing.

A schematic view of the Allair jig is shown in Figure 7.

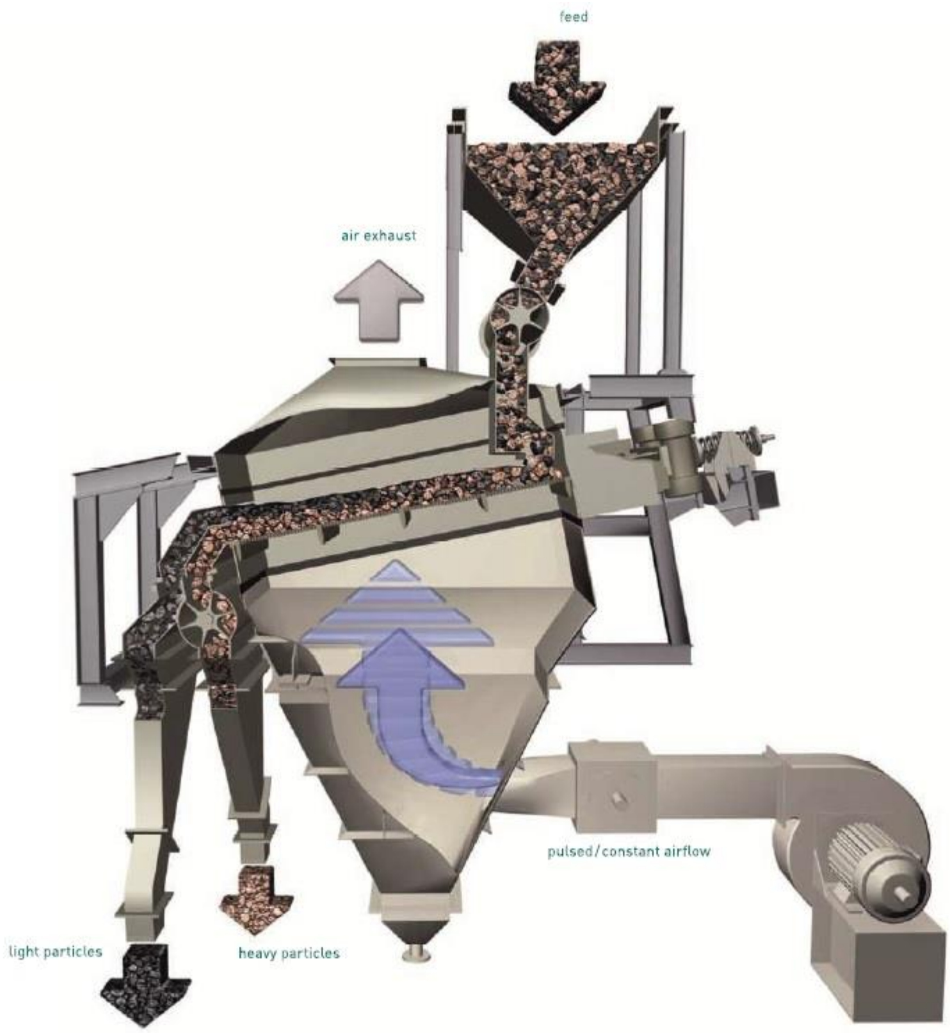

Figure 7: Schematic view of Allair jig

The Allair jig consists of an inclined, perforated vibrating table. A controlled flow of raw coal is fed onto the bed via a star gate and the coal on the table is fluidized by a constant flow of air supplied by a fan. Pulsating air is also supplied via a flutter valve and this provides a jigging action to the bed which allows the coal to stratify according to the density of the particles. Lighter particles migrate to the top of the bed and are discharged onto the product conveyor. The heavier discard particles move to the bottom of the bed. A nuclear density gauge and a second star gate are used to control the thickness of the layer of discard coal in the bed. A close-up view of the controller and star gate is shown in Figure 8.

Fine coal and dust is carried out of the bed by the air flow and is captured in a cyclone and bag filter arrangement. The fine coal can be added back to the product if the quality of the coal is acceptable.

Figure 8: Density gauge and star gate for controlled removal of discard

Advantages of dry processing

The main and most obvious advantage of dry processing of coal is that no water is required. The fact that the coal remains dry improves the heat value of the coal as opposed to wet processes where the final product is wet. In some cases, coal and the associated shale may become friable when wet or if the coal is porous, it could absorb moisture during wet processing. In the case of dry processing, neither of these issues is a problem.

The capital as well as the operating cost of dry processing is significantly lower than that of conventional wet processing plants. The capital cost of a dry plant may be as low as half of that of a conventional plant and the operating cost also about half that of wet processing plants.

Dry plants are easy to construct and the construction time is much shorter. Since there are no water circuits and slurry ponds required, issues with permits are also less. Dry processing plants can also be made semi-mobile allowing fast and easy relocation of these plants.

Disadvantages of dry processing

The major drawback of present dry processing techniques is the poor separation efficiency and the high cut-point density. It is also difficult to control the quality of the product from dry coal processes. This limits the application of these technologies to de-stoning operations on easy-to-process raw coals. Typical, normalised, partition curves for an X-ray sorter and a FGX are shown in Figure 9.

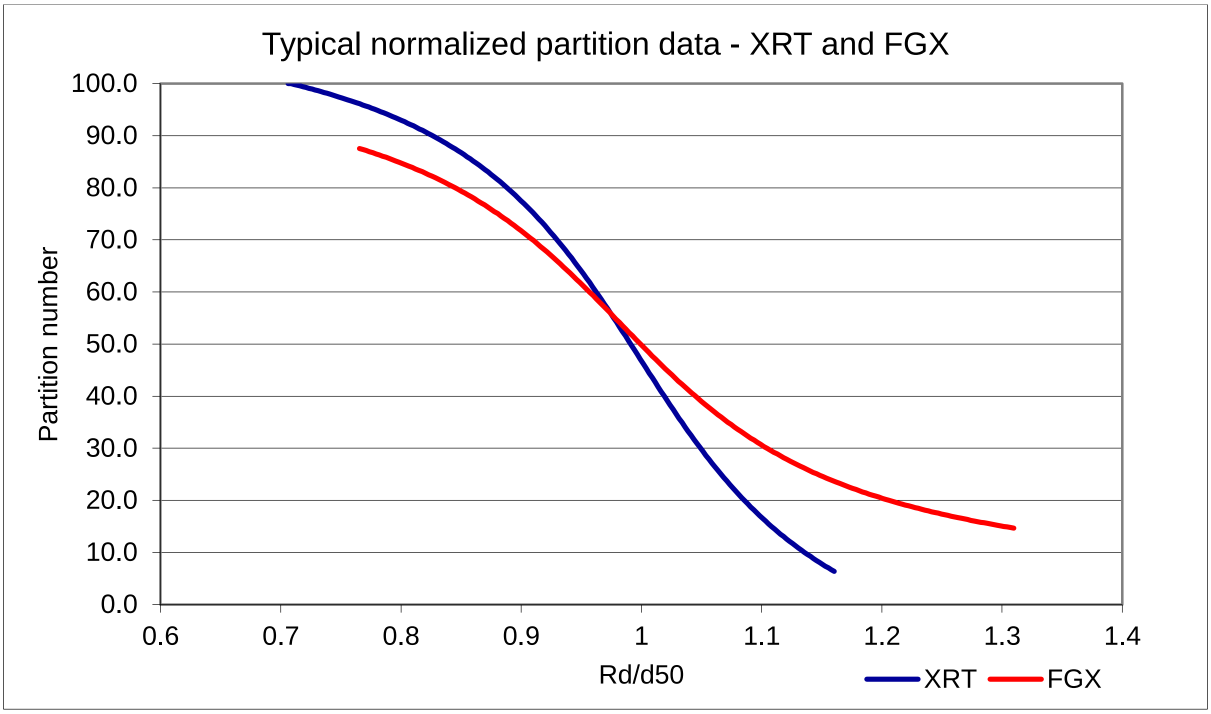

Figure 9: Typical normalised partition curves for a FGX and X-ray sorter

The process is also not effective on finer coal and in practice, it is better to remove the minus 6 mm from the feed to a FGX and the minus 30 mm from the feed to an X-ray sorter. To remove the fine coal from the plant feed requires dry screening and for this purpose, screens such as the Bivitec and the Liwell have to be used. Coaltech conducted test work on dry screening with the Bivitec screen and found that these screens do work well – provided the coal is dry. When the coal fed to these screens is damp, screening becomes very difficult and inefficient. When the coal is dry, dust can become a problem. Figure 10 shows a Liwell screen installation at a colliery in Mpumalanga.

Figure 10: Liwell screens for dry screening of coal

Current status of dry processing in South Africa

The dry processing technologies evaluated thus far have proven viable in certain, specific applications. The FGX and the Allair jig are both capable of processing raw coal in order to remove stone and shale contamination and to make the coal suited for use by Eskom. X-ray sorting is well suited to de-stone coarse run of mine coal. The process will most probably find application in cases where coal containing high amounts of stone inclusions is mined. The X-ray sorter can be employed close to the mining operation to remove the stone and shale from the raw coal, yielding a less contaminated raw coal which can then be transported to a preparation plant for further processing. By removing the stone contamination close to source, a saving in transport cost as well as a saving in processing cost is obtained.

Dry processing is, however, not applicable on all mines and with all coal types. The application of the technology needs to be assessed in each case. The low capital and operating costs may be very attractive, especially for small mines, but may lead to unrealistic expectations. It is therefore necessary to consider the separation efficiency of the process for each specific application. In order to illustrate that low capital and operating cost are not the only considerations when choosing a processing route, a hypothetical case study is presented.

A comparative financial evaluation was carried out to illustrate the potential economic advantage or disadvantage of using dry processing to prepare coal for power station use when processing raw coal from the No. 2 Seam of the Witbank coal field. The evaluation compares dry processing to dense medium processing of the same coal. A hypothetical mine with a ROM production of three million tonnes per year was used as the basis. It was assumed that the mine produces a product with a calorific value of 21 MJ/kg (air-dry) and that this is done by crushing the raw coal to a top-size of 50 mm, screening the coal to remove the minus 6 mm and processing only the plus 6 mm fraction. The minus 6 mm size fraction constitutes 30 % of the feed coal. The raw minus 6 mm coal is assumed to have an ash content of 30% and a calorific value of 21 MJ/kg.

The plant is in operation for 6000 hours per year and therefore the nominal capacity of the plant will be 500 tonnes per hour. Of this tonnage, 30% (150 tonnes per hour) is minus 6 mm coal which will be dry-screened from the feed and sent directly to the product conveyor. The plus 6 mm coal will be beneficiated and the required capacity of the coarse coal processing equipment is therefore 350 tonnes per hour. For the dry processing option, a FGX will be employed and for the dense medium option, a dense medium cyclone. The washability of the plus-6 mm size fraction coal is given in Table 1.

Table 1: Washability data for 50 x 6 mm coal

Relative Density		Yield %	CV MJ/kg	Ash %
F @	1.4	2.8	28.2	10.7
F @	1.5	14.1	25.4	18
F @	1.6	18.3	23	22.7
F @	1.7	17.9	19.6	32.2
F @	1.8	10.3	16.6	39.3
F @	1.9	6.8	15.2	44.4
F @	2.0	4.9	12.5	50.1
F @	2.1	3.5	7.8	61
F @	2.2	4.2	5.9	66.2
F @	2.3	5.6	2.6	72.7
F @	2.4	3.3	2.2	76.5
S @	2.4	8.5	0.3	78.7
Raw		100	16.18	40.4

Simulated processing of the coal with a FGX and a dense medium cyclone respectively results in the following yields, qualities and efficiencies.

Table 2: Comparative processing results on + 6 mm size fraction

Parameter	FGX	DM
Feed % Ash	40.4	40.4
Product % Ash	30.65	28.56
Product CV (MJ/kg)	20.12	21.00
Discard % Ash	52.3	69.5
Product Yield	55.0	71.0
D50 cut-point RD	1.80	1.91
EPM	0.252	0.023
Organic Efficiency %	71.1	99.8
Sink in float %	8.9	0.6
Float in sink %	17.1	0.3
Total misplaced %	26.0	0.9
Near-dense material	17.1	11.2

The final product, inclusive of the raw minus 6 mm coal, has the following qualities

Table 3: Final product quality and yield

Parameter	FGX	Dense medium
Product total moisture %	7.5	10.4
Product CV (MJ/kg air dry)	20.51	21.00
Product CV (As received)	19.69	19.54
Product yield (% of plant feed)	68.54	79.75

As expected, the dense medium process product yield is significantly higher than that of the FGX. The FGX also fails to produce a 21.0 MJ/kg product, since a cut-point density of less than 1.80 is required which is normally not possible with this type of equipment. Due to the lower moisture content of the FGX product, though, it has a slightly higher as-received heat value than the dense medium product. The lower yield obtained from the dry process may be, to some extent, off-set by the lower capital and operating cost. However, the question is whether it is economically viable in the longer term to implement dry processing. The following analysis aims to answer this question.

To facilitate the comparison, approximate capital and operating costs are assumed and listed in Tables 4 and 5.

Table 4: Approximate capital and operating cost (Rand)*

Type of Plant	Capital cost (Rand/tonne per hour feed)	Operating cost (Rand per feed tonne)
FGX	R 50 000	R 5.50
Dense medium cyclone	R 200 000	R 17.00

**These costs relate only to the processing plant and exclude crushing/screening of raw coal and disposal of rejects*

Table 5: Other operating costs

Item	Cost (Rand)
Mining cost - Rand per ROM tonne	R 100.00
Crushing/screening of ROM	R 2.50
Disposal of discards – Rand per tonne	R 2.50

The capital and operating costs shown in Table 5 relate to the processing plant only. The raw coal preparation and handling as well as the product handling systems will be similar for both types of plant – it is assumed that the capital cost of the raw coal crushing and screening section and the product handling section amounts to R15 million. Operating costs are as shown in Table 4. Using the capital cost shown in Table 4, the comparative capital cost for a FGX plant and a dense medium cyclone plant to process 350 tonnes per hour of plus 6 mm raw coal will be:

Table 6: Capital cost (Rand)

Dry processing	Dense Medium
R 17 500 000	R 70 000 000

It is assumed that the product coal is sold on a FOR (free-on-road) basis at a price of R 8.70 per gigajoule. The product from the FGX, due to the lower moisture content, has a heat value of 19.69 GJ per tonne (on an as-received basis) compared to that of the dense medium product at 19.54 GJ per tonne. The FGX product selling price is thus slightly higher than that of the wetter coal from the dense medium process – R 171.28 per tonne versus R170.00 per tonne. Using the data shown above, and an interest rate of 12% for borrowing capital, the result values shown in Table 7, result from an economic analysis of the two processing options. The tonnages and yield values shown in Table 7 are expressed on an air-dry basis but the sales revenue is calculated using as-dispatched tonnes.

Table 7: Outcome of financial calculations

Case	Dry processing	Dense medium
Product t/annum	2055000	2391000
Discard t/ annum	945000	609000
CV of product (MJ/kg)	20.51	21.00
Ash content of product	30.37	30.00
Surface moisture of product	4.0	7.0
Inherent moisture of product	3.6	3.7
Total moisture of product	7.46	10.44
FOR price/tonne	R 171.28	R 170.00
Sales revenue per annum (x 1000)	R 366 646	R 437 064
Operating cost per annum: (x 1000)		
Mining	R 300 000	R 300 000
Crushing & screening	R 7 500	R 7 500
Processing	R 11 550	R 35 700
Discard disposal	R 2 362	R 1 522
Total operating cost per annum	R 321 412	R 344 722
Capital expenditure:		
Processing plant	R 17 500 000	R 70 000 000
Raw coal / product handling	R 15 000 000	R 15 000 000
Total capital cost	R 32 500 000	R 85 000 000
Contribution per annum	R45 233 750	R92 342 016
Payback Period (years)	0.72	0.92
Return on Investment ratio	0.39	0.09

The results show that the FGX option has a shorter payback period than the dense medium option and it furthermore has a higher return on investment ratio. The contribution per annum, due to the lower product yield, is however much lower than that of the dense medium option. The net present value (NPV) of the two investments over time is summarized in Table 8 and shown graphically in Figure 11.

Table 8: NPV versus time

Years	FGX	Dense medium
1	R 7 887 277	(R 2 551 771)
2	R 43 947 345	R 71 062 719
5	R 130 557 546	R 247 872 302
10	R 223 080 776	R 436 752 986
15	R 275 580 942	R 543 928 959
20	R 305 370 946	R 604 743 484

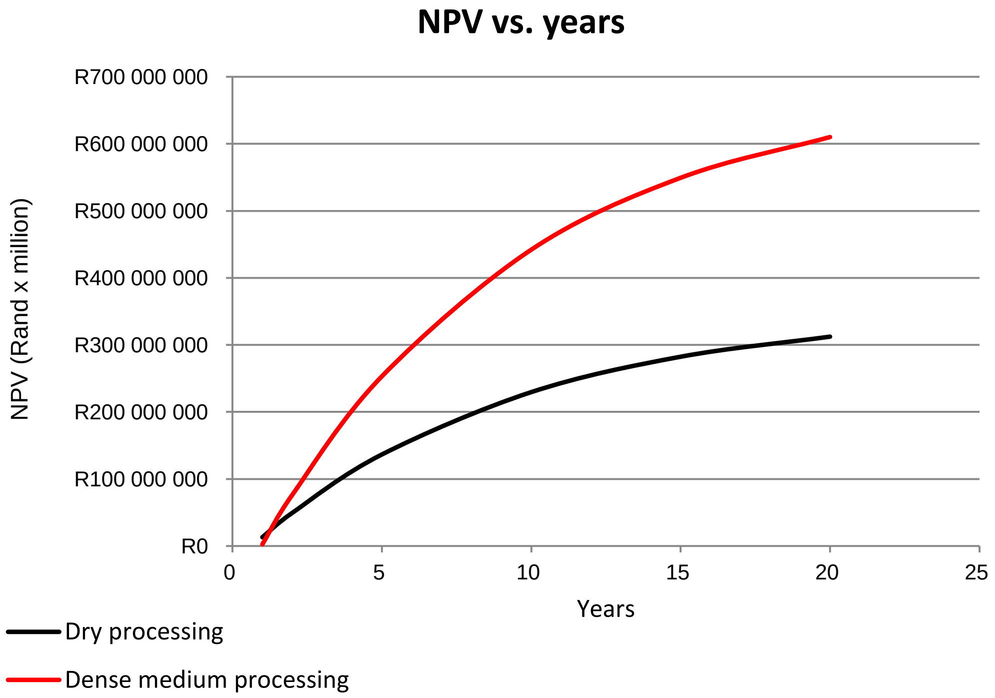

Figure 11: NPV versus Time

The low capital and operating cost of the FGX option result in a positive NPV value at the end of year 1 whilst the dense medium option still shows a negative NPV. However, after year 2, the dense medium option has a higher NPV value than the dry processing option. The dense medium option's NPV continues to increase as a higher rate than that of the dry processing option due to the higher annual contribution.

It therefore seems, from the analysis carried out, that dry processing of coal is a good choice for short-term projects – for example re-working of discard dumps or processing of small coal reserves. For longer term projects, dense medium processing is more economical, despite the higher capital and operating costs.

The example presented here is intended only to illustrate that low capital and operating costs alone are not always reason enough to implement specific technologies since the loss of product yield due to low recovery efficiency can more than offset the advantage of low cost. The case presented is very specific and should not be considered the norm since a number of other considerations should be kept in mind namely:

- The availability of water for processing
- The location of the mine and the customer
- The specific nature and washability characteristics of the raw coal
- The specifications and price of the product coal
- The degree of control of product quality required and the implications of delivering out of specification coal
- The availability of electricity and other infrastructure
- The duration of the project

Dense medium offers the best control over the product quality whereas it is very difficult to control the quality of the product from the FGX and this should be taken into consideration when deciding on the appropriate processing technique to opt for in a specific case. If no water is available for wet processing of coal, then the FGX becomes the only viable option. In the case of projects where the duration is short, for example the reclamation of coal from a discard dump, which may last only a few months, the FGX becomes a logical choice for a number of reasons listed below:

- The FGX plant can be constructed in a very short time
- The necessary environmental clearance is much less complicated than for wet processing plants
- Almost no infrastructure is required – a small FGX plant can be run from a portable diesel generator
- The plant can be easily and inexpensively re-located after completion of the project

Conclusion

Dry processing equipment is inexpensive to purchase and operate but does not provide efficient separation. It will not always be able to upgrade raw coal to the required quality – especially when the coal contains high amounts on near-dense material. In specific cases, where the coal is easy to process, where there is a shortage of water and when only de-stoning of the coal of the coal is required, dry processing technologies may prove the most viable option. It is, however, necessary to consider all aspects of each application.

Coaltech has conducted research on dry processing and screening methods since 2008 and the FGX, X-ray sorter and the Bivitec screen were evaluated in some detail. From a research point of view, the work may be considered done but implementation of the technologies has only started. As stated earlier in the report, implementation of the different dry screening and processing technologies can be complex and the technologies will not work in all cases. Careful evaluation is necessary for each application.

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