Process design of the Phola coal preparation plant

by G.M. Cresswell*

Synopsis

The 2 360 t/h two module Phola coal preparation plant represents a new era of large plant in the Witbank coalfield designed to extend its life to 2020 and beyond. The plant uses the optimum processing model for Witbank coals, receiving a feed coal size of -50 mm, wet screening it into coarse and small coal fractions 50 x 12 and 12 x 0.63 mm before processing them in parallel through two primary DM cyclone sections, in order to make a 27.5 MJ/kg export floats product. The sinks are processed through a common high density DM cyclone section to produce a 21.5–23 MJ/kg thermal coal middlings product. The plant design incorporates the largest size DMS equipment used to date in South African coal preparation plants, i.e. 1 150 mm large diameter pump fed DM cyclones and 4.2 m width banana screens. The fine coal is conventionally processed by spirals, whereas the raw coal slimes are filtered using automated plate and frame filter presses and added to either the middlings or discards depending on its quality. The paper describes the database, innovative design concepts, construction, and commissioning.

Introduction

The design of the Phola coal preparation has its roots in the late 1980s when there was a requirement for a plant to treat 8 Mtpa coal from Ingwe's (now BECSA's) adjacent Klipspruit opencast mine at Ogies, Mpumalanga. The mine is part of the South African Witbank Coalfield and accesses the No. 2 and 4 Seams with some 5 Seam material.

The design brief was for a classic two-stage Witbank plant producing a prime 27.5 MJ/kg export product and a 21.5–23 MJ/kg middlings for the nearby Kendal power station.

The plant concept doubled in size when Anglocoal formed a 50:50 JV with BECSA for a plant which would also treat coal from their new Zondagsfontein underground coal mine, approximately 15 km to the south. The advantages of a combined plant lay mainly in the access the Klipspruit plant gave to the Richard's Bay coal terminal railway line and lower operating costs, as a combined plant allowed a larger unit module size while still keeping the flexibility of a multi-modular design. This has resulted in the design, construction, and commissioning of one of the largest and most modern coal preparation plants built in the area for 30 years.

The last era of large plant construction in the Witbank and adjacent coalfields was during the mid 1970s–early 80s (Cresswell, Salter 2006). This period also saw the construction of the Richard's Bay Harbour Coal Terminal, the export railway line from Witbank and Highveld coalfields and most of South Africa's modern power stations. Besides providing 65–72 Mtpa export coal, the Witbank coalfields account for approximately 80% of South Africa's power requirements.

The Phola plant design is a logical extension of past practices and makes use of advances in equipment size, control systems, and design concepts, some of which have been pioneered overseas during the intervening 20 years. This paper discusses those aspects of the design which are innovative and applicable to future plants as well as comments on current performance as measured in a recent efficiency test.

Database

As the Klipspruit mine has been operating for a number of years and trucking its coal to another washing plant, there existed an easy opportunity to take bulk samples. A total of 32 were taken over an 18-month period for washability analyses with most of the samples being split into 80 x 12 mm and 12 x 0.5 mm fractions. From the Zondagsfontein reserve, numerous small borecore samples were made available as well as three large core samples and a bulk sample from an adjacent coal

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reserve. The size distribution range from the bulk and other samples are shown in Figure 1 following simulation of -50 mm crushing.

It can be observed that the current feed to the plant from performance tests on each module is coarser than that allowed for (De Korte 2010). However, this has had little impact on the plant design as the corresponding yields have

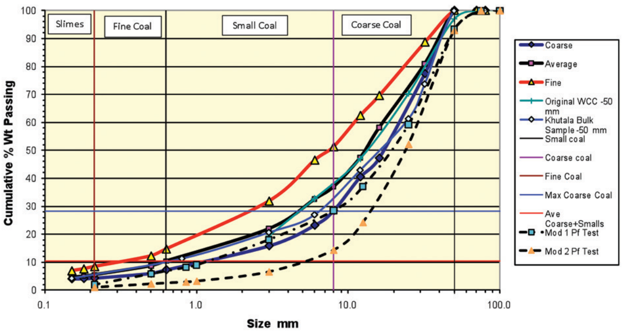

Figure 1—Size distribution ranges from 22 bulk samples

been in the average to maximum range, allowing the extra coarse coal to report straight to the export conveyor after passing through the primary DM cyclone vortex finder.

The bulk samples provided an invaluable database for not only calculating the yield ranges for the whole plant but also investigating the difference in yields that could be expected between the coarse and small coal fractions. For these calculations, use was made of a DRA in-house DM cyclone simulation program to calculate the expected primary and secondary yields. These are illustrated in Figure 2 alongside similar calculations from the Zondagsfontein database simulations.

The wider variation in product yield that can be expected from the Zondagsfontein coal can clearly be seen.

When the target products are calculated from the Klipspruit bulk samples, the enhanced small coal yield of approximately 20% can clearly be seen in Figure 3.

It is interesting to note that the coarse coal yields are lowest when it constitutes the greatest proportion of the raw coal feed, whereas the opposite is true of the small coal fraction. It is believed that this can be explained by the fact that the lower yields are due to a higher ash content, which in turn comes from a harder coal. Thus the higher the ash

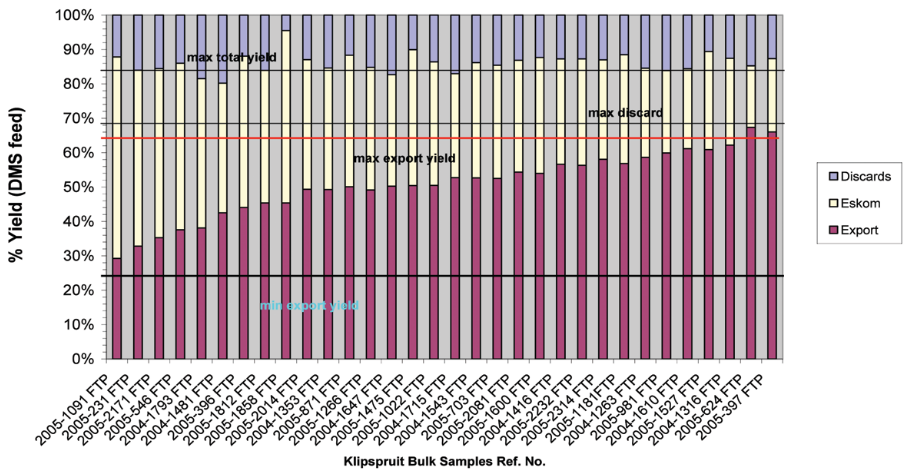

Figure 2a—Simulated primary (export), secondary (Eskom), and discard yields—lipspruit opencast mine

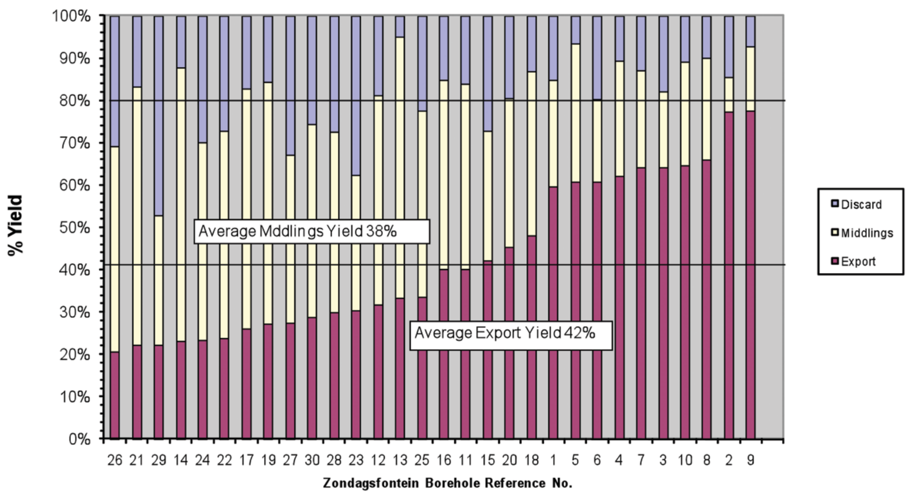

Figure 2b—Simulated primary (export), secondary (Eskom), and discard yields—Zondagsfontein underground mine

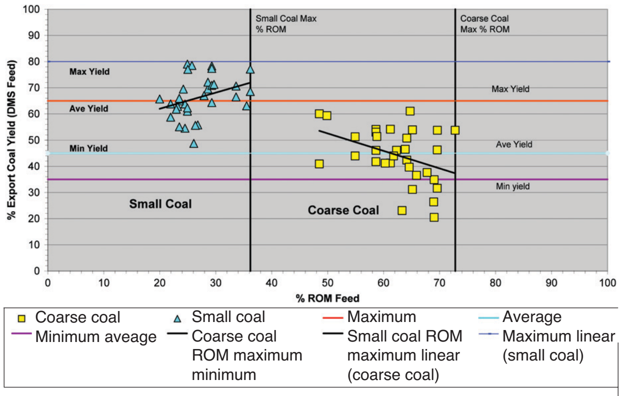

Figure 3—Simulated coarse and small coal export product yields

content, the greater the proportion of coarse coal 50 x 8 mm in the raw coal. The difference in yield is shown clearly in Table I from measurements taken during the performance tests.

Previous plant design concepts

The overall concept of a two-stage low density separation followed by a high density DMS plant was quickly settled on due to the yield distribution of the bulk samples that showed up to 65% of the coarse and 80% of the small coal could become an export product. This process model also allows the density to be set for each product and therefore both product qualities can be directly controlled.

There was also a requirement that the Klipspruit coal be allowed to bypass the plant completely and report to the middlings product. This resulted in a 'bypass conveyor' cutting through the whole site and becoming one of the dominating aspects of the overall layout as the process plant and stockpiles were constrained by the local geography into a long rectangular slot, with Klipspruit mine in the east and the rail loadout silos approximately 3 m to the west.

Having settled on the process concept, various studies ranging over five years proposed solutions such as using multiple single product modular plants in parallel, to the more conventional solution of a large multi-product plant. The early designs also incorporated the flexibility to take out a primary sinks or 'raw middlings' product and to introduce a raw coal directly into the secondary stage, as well as a generous allowance for surges. Space was left in the design for a future flotation plant and throughput expansion by 50%. This coupled with the requirement not to use equipment any larger than was in current South African use, which in practice limited the screen sizes to 3.6 m width and the DM cyclone to 1 000 mm diameter, led to a large and expensive design for the 8 Mtpa Klipspruit plant by the end of 2004.

Final plant design concepts

When the plant size was effectively doubled by Anglocoal's Zondagsfontein Colliery joining the project, the design team quickly concluded that they had to start from scratch as a simple doubling up of the plant led to almost insurmountable materials handling problems on the restricted site.

The key to reducing the plant footprint and significantly lowering the capital costs lay in two relatively simple concepts—firstly the maximum equipment size allowed was extended to include proven sizes from overseas (principally Australia where many reference sites were visited) and, secondly, to simplify the process such that all the coal was washed and no intermediate product was allowed to be withdrawn or added. The key concept of separating the coarse and small coal fractions in order to optimize the yield was retained, as this allowed the module size to increase in overall throughput.

The maximum equipment size settled upon was 4.2 x 8.3 m banana screens and 1150 mm DM cyclones for the coarse coal and secondary high density separation. These sizes were well proven in Australia by early 2005. This allowed the plant to be enormously simplified into a two module plant of 1180 t/h capacity per module. It was interesting to note that the footprint of the final 16 Mtpa plant design was smaller than the previous 8 Mtpa plant, which consisted of 5 major processing sections. Smaller 710 mm diameter cyclones are used for the small coal primary separation to ensure that the separation efficiency is maintained.

The final flowsheet is given in Figure 4 and overall mass balance in Figure 5.

Innovative plant design concepts

Primary sinks static panels

A key point in the final plant design was the internal arrangement to combine the primary sinks from both coarse and small coal sections and deliver them to the high gravity section mixing box. This is achieved by the use of static drain panels (the old DSM method was to use double sieve bends) rather than vibrating screens, as the advantage lies in not only the saving in equipment and vibrating load on the structure, but also in the fact that on a crash stop (which are all too frequent in the Highveld summer lightening storms) the coal will sit in on the static screen rather than be discharged into mixing box feed launder and potentially cause a blockage on start-up.

Once the concept was agreed, the design problem was what angle to set them at and how much drainage capacity to allow for, as the coal needs to slide down the screen while the medium drains and then gently drop off into the collecting launder.

Table I

Measured plan yields

Plant section	Module 1 export yield		Module 2 export yield	
	Stage	Plant	Stage	Plant
Pri coarse	56.2	35%	68.6	52%
Pri smalls	71.8	22%	85.2	18%
Sec HG	40.0		48.7	
Fine coal	41.8	2%	36.0	1%
Total		59%		71%

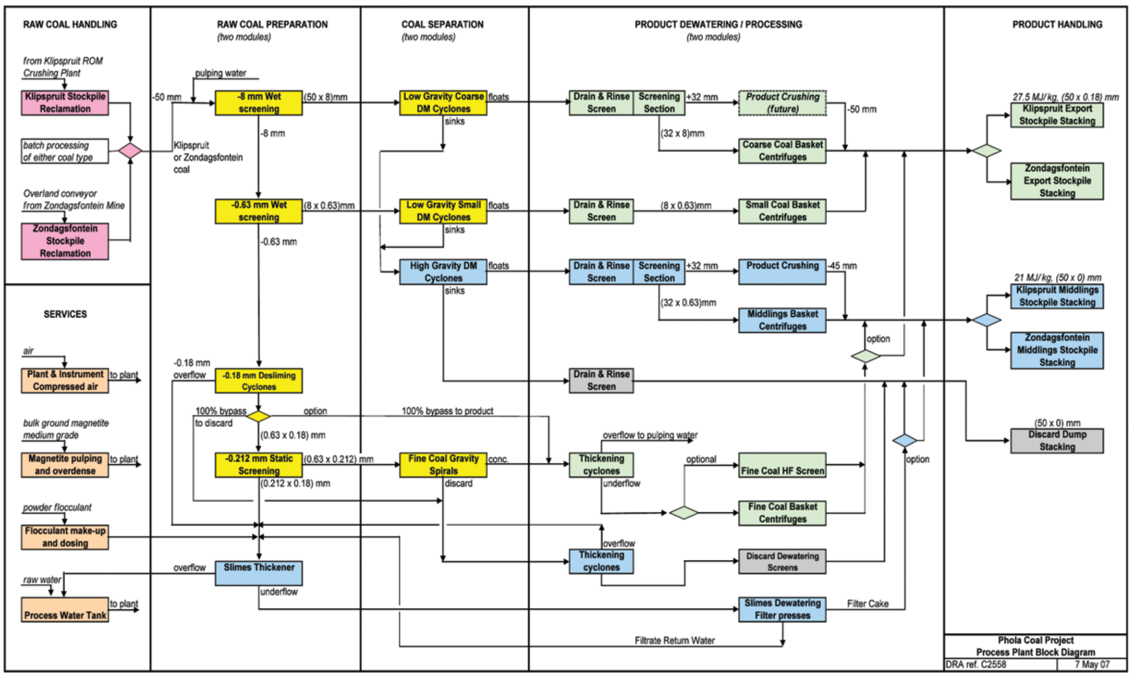

Figure 4—Final design concept block diagram

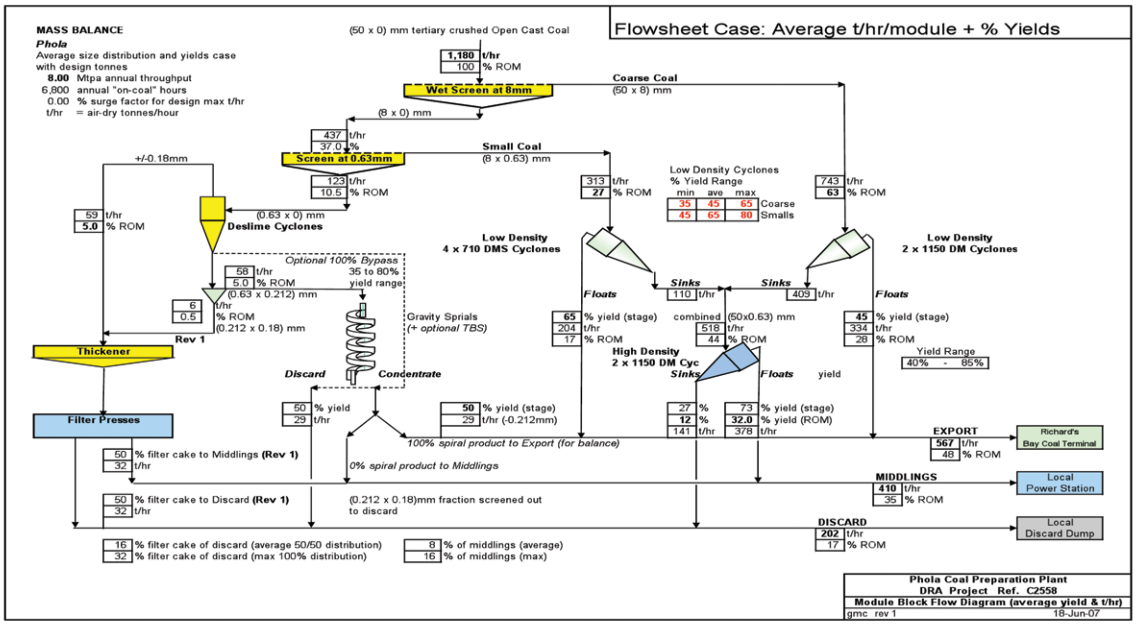

Figure 5—Overall design average mass balance

Note was taken of the method adopted at the Mafube plant where a similar design concept was used by DRA but with an adjustable screen height and linked to the raw coal feed control system. At Phola where the tonnage is at least 25% greater, having an adjustable screen would have been an unwieldy option, so instead a generous 50% extra area was allowed using a 30 degree slope for the coal to settle on. The main design challenge here was not so much the concept or equipment sizing, but ensuring even distribution to the screens due to the huge volume of material going through the module.

This scheme is illustrated in Figure 6.

Elevated cyclone feed pumps

When one lays out a pump fed DM cyclone plant, there is generally scope to elevate the DM cyclone feed pumps as the height of the plant is dictated by the gravity flow of material from the DM cyclone floats to the drain panel, drain and rinse screen, dewatering centrifuge, and product conveyor. Given the size of the Phola plant, there was an opportunity to save approximately 15 m in pumping head by elevating the pumps

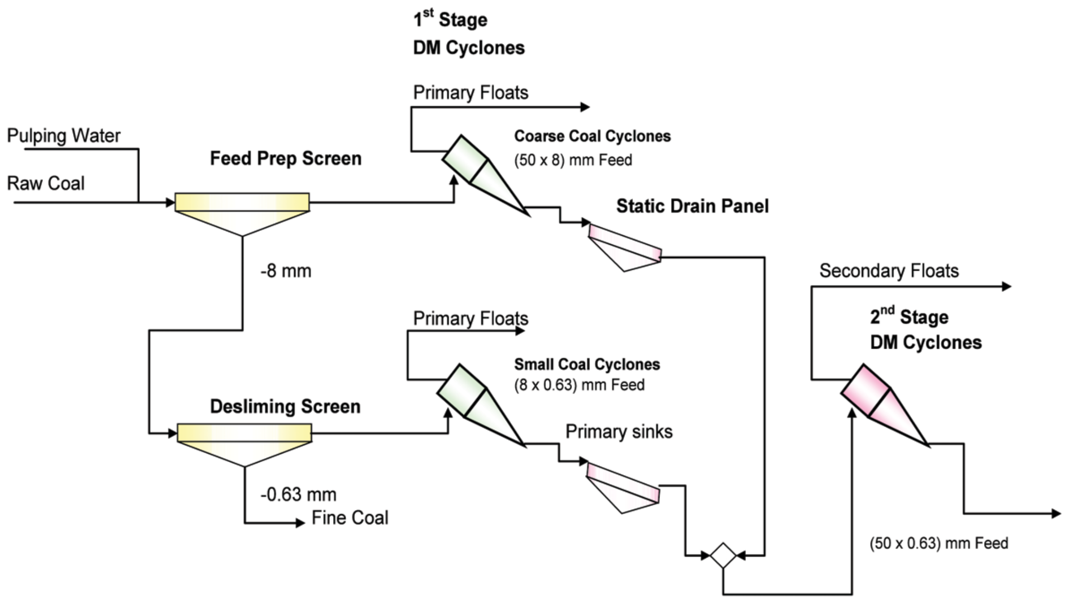

Figure 6—Primary sinks process concept

and mixing box above the ground floor (Figure 7). There is also the considerable advantage of being able to drain the mixing box directly into the CM sump on a crash stop, allowing for a quick start-up.

Protection panels above the CM sumps

This is a concept in common use for Australian plants, which involves making sure that all the return flows into the sumps which could contain coal, drain through a static drain panel (Figure 8) of sufficient aperture directly above the sump. The idea being to firstly stop any large coal entering the medium, then for this coal to be shovelled over the side of the sump in a controlled manner onto the floor for pick up. Normally return lines are routed directly back into the sump, but if this concept is followed, it has a considerable impact on the layout, not necessarily adding height but complexity in gathering all the drain lines into a discharge box immediately before the CM sump.

Use of 'Pachuca' valves for medium sump agitation

These air agitation valves, originally designed for the SA gold industry leaching tanks, are situated in the centre of the bottom of the sump with the air being fed to them through the sump or preferable under the sump if the layout allows. They are self-sealing by a double lock cone system and because they introduce agitation air into the middle of the sump rather than at the sides, they appear to be far more effective and have eliminated start-up problems due to settled magnetite.

Filtration of the slimes

It was integral in the design concept to filter the slimes in order to reduce the fresh water requirements and enable the filter cake to be added to either the middlings or discards.

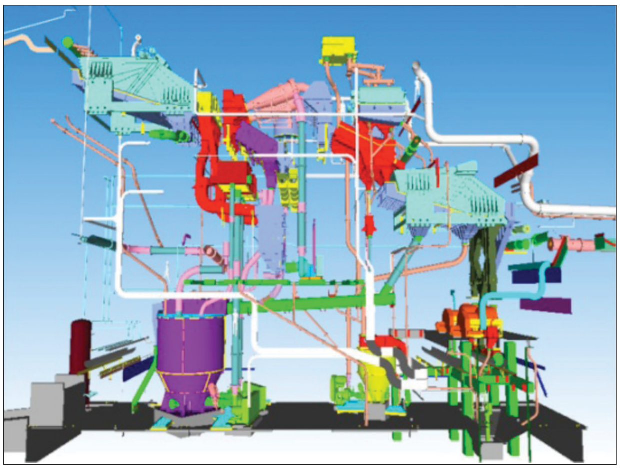

Figure 7—Section through LG coarse coal cyclone section

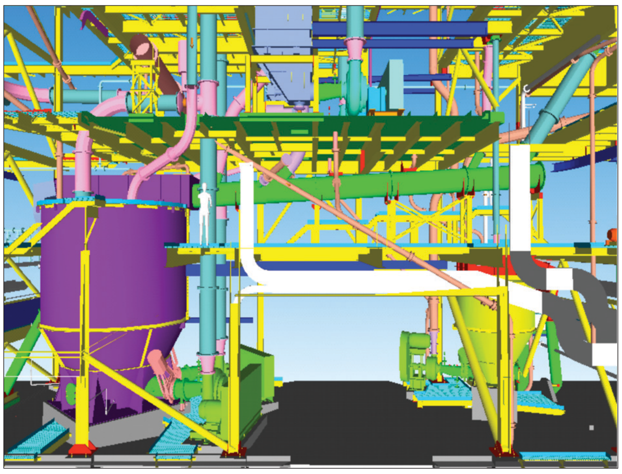

Figure 8—Medium drain line back to CM sump

Given the maximum design tonnage involved, (188t/hr) the different qualities of the raw coal slimes from the two different mines and the requirement to produce as dry as possible filter cake when it was to be added to the middlings, the duty was split equally between two filter types—the TH filter with its single cloth per plate and the continuous cloth Lasta filter, which also incorporates a membrane squeeze in its operation. Both these filters are relatively new models in the South African coal industry, with the Lasta being far more automated and complex in both design and operation; but successfully proven at the AngloCoal Goedehoope flotation plant.

The filters are laid out at right angles to the product belts and by using reversible conveyors, the filter cake can be fed to either the discard or middlings belt. There are six filter cake conveyors and 9 filters and, given the variability in the time they can take to complete the filtration cycle, a dynamic simulation modelling exercise was carried out to calculate the maximum filter cake that could be added to the products and the optimum speed the filter cake and product conveyors should run at.

Plant mass balance

A detailed coal-water-magnetite mass balance was calculated for the wet plant using an Excel spreadsheet. Besides being used for pump and pipe sizing, it was used to calculate the maximum flow conditions for the many variables that the plant could experience, e.g. average flowrate, minimum/maximum medium densities, maximum yield for the maximum coarse, smalls, fines and slimes sections, the 'no coal' condition, and the gravity spirals' bypass condition. This had been calculated for the coal solids, as shown in Figure 5, but these simulations gave the maximum volumes and allowed the pump and pipe sizes to be finalized.

The mass balance was split into the five main sections of the plant—coarse low gravity, smalls low gravity, high gravity, fine coal and slimes. The balance for each section was calculated separately as well as an overall balance for coal, water and magnetite in both t/h and m^3/h.

Process equipment selection

As stated earlier the original design brief was not to use any equipment or size of equipment not fully proved in South Africa, therefore the type of equipment selected tended to be conservative in terms of manufacturer.

The most notable area in which the design boundaries were pushed was the screen capacities through the use of modern banana screens. These screens with their multiple angle decks allow previous capacity standards in terms of t/h coal/m^2 screen area to be greatly exceeded due to the velocities achieved on the screens and the thin bed layers. Particular care was taken in the design of the feed boxes ahead of the screens in order to spread the feed slurry as evenly as possible across them. In this area in particular, the designs from previous plants built by DRA such as Mafube were carefully scrutinized and further developed.

The most conservative equipment selection was in the filter presses where 50% extra design capacity was allowed since there is no slimes dam. Filter cake surface moistures averaging around 20% are being obtained from the units, but can vary according to the amount of clay in the coal, to as much as 16–25%.

Use of Autocad during design

Full use was made of an Autocad 3D model during the design phase in order to optimize the layout (Figures 7 and 8). The model allows a 'walk' through the plant which was invaluable in seeing where access needed to be allowed for maintenance and for the efficient running of pipes through the plant.

Linings and pipe materials

All boxes, lower sections of pump sumps, and pump suctions that are in contact with coal were ceramic lined with thicknesses varying from 12.5 mm up to 50 mm for spigot boxes. All pipes handling magnetite medium were basalt lined, whereas other slurry pipes used HDPE.

Nearly all screen and drainage panels are of HDPE construction with some use being made of the 'polywedge wire' panels, which offer larger open area and similar ease of replacement to that of HDPE panels.

Plant control

The plant is fully automated with a 'Profibus' SCADA system allowing the control room operators to run the full plant from the raw coal stockpiles, process plant, product stockpiles and rail load out.

Plant construction, safety, and commissioning

The plant construction was notable for the very poor ground conditions it encountered. In effect the plant was built on a series of concrete rafts supported on 15 m piles. The peak of the construction effort for the civils coincided with the heaviest monthly rainfall experienced for many years; then the following year when the mechanical erection was at its peak, even heavier rainfall was recorded. This led to an abnormal number of claims for rainy days.

Despite these conditions there were only two LTI (lost time incidents) during construction and an LTIFR frequency rate of 0.14 was achieved over 2 800 000 construction man-hours (compared to the local industry average of 0.5).

Commissioning proceeded relatively smoothly. The main problem was to get the slimes thickening and filtration system working in the face of crash stops due to power cuts and uneven feedrates. This led at times to running only filter cake out of the plant, which in turn has led to modifying the discard bin discharge system. A decision was made to change from a swing chute to a full width clam shell gate to counter filter cake hang-up which can stretch over a 3 m gap. It was concluded that it is unrealistic to expect the plant to never run filter cake alone, as had been originally specified.

Final plant performance vs. design

Both modules have been run consistently at 100% of design capacity and the results from the plant performance tests are shown in Table II.

Table II

Results of the plant efficiency tests

Phola module 1 and 2 performance test results (March 2010)										
Parameter	Unit	DMS section						Fine coal	
		Primary coarse		Primary smalls		Secondary HG		Spirals	
		Mod 1	Mod 2	Mod 1	Mod 2	Mod 1	Mod 2	Mod 1	Mod 2
Feed size range	mm	(65 x 12)	(65 x 12)	(12 x 0.63)	(12 x 0.63)	(65 x 0.63)	(65 x 0.63)	(2.0 x 0.1)	(2.0 x 0.1)
Mean feed size	mm	28.6	28.6	3.0	4.4	7.7	12.9	0.4	0.4
Plant feed	%	62.9	75.8	30.0	21.6	36.0	27.0	5.1	1.6
Cyclone diameter	mm	1150	1150	710	710	1150	1150	MX	MX7
Cyclone geometry		hi capacity	hi capacity	standard	standard	standard	standard	n/a	n/a
Inlet pressure	kPa	160	163	95	95	175	182	n/a	n/a
Medium: ore ratio (ave)		4.1	4.1	5.6	5.6	6.0	6.0	n/a	n/a
Cyclone D	D	9.5	9.5	8.5	8.5	9.1	9.0	n/a	n/a
Medium SG	t/m³	1.50	1.52	1.60	1.61	1.70	1.80	n/a	n/a
D_{50} cutpoint	t/m³	1.61	1.62	1.72	1.74	1.83	1.82	1.60	1.63
Cutpoint density offset	t/m³	0.11	0.10	0.12	0.14	0.13	0.02	n/a	n/a
e pm		0.020	0.016	0.016	0.018	0.022	0.019	0.378	0.345
Guarantee		*0.023*	*0.023*	*0.026*	*0.026*	*0.026*	*0.026*	*n/a*	*n/a*
Feed ash	%	30.9	24.1	27.8	21.4	53.3	44.6	29.5	31.5
Stage yield	%	56.2	68.6	71.8	85.2	40.0	48.7	41.8	36.0
Product ash	%	15.4	13.6	15.8	16.0	36.0	30.3	20.6	17.0
Discard ash	%	50.9	42.6	58.3	52.4	64.9	58.2	35.8	39.7
Total misplaced material	%	4.05	1.06	1.57	1.5	5.04	3.02	40.2	37.0
Near density material	%	22.2	23.8	13.0	9.8	30.8	27.5	22.3	28.3

The original design large coal/small coal split size of 8 mm design has been increased gradually to 12 mm in view of the coarse nature of the coal being outside the original design concept. This has had no deleterious effect on the plant capacity.

The efficiency results for the DM Cyclones are well within the manufacturer guarantees as shown above, a factor that it is believed can be largely attributed to the medium : coal ratio being within established norms for large cyclones. Long term magnetite consumption figures are not yet available. It can be seen that the spirals are not performing efficiently, a common problem in the Witbank coalfield when using spirals only, however, space was allowed within the plant design to add extra processing units such as a TBS separator to improve the performance if required. The long-term feasibility of adding the filter cake to the middlings product is still being evaluated in terms of Eskom requirements and handling capabilities.

Conclusions

Following an unusually long conceptual design and study period, one of the largest throughput Witbank coal plants built for many years has been successfully commissioned and is operating within its design criteria. The complexity of the entire integrated joint venture complex has meant there was a long period of operator familiarization but the plant operation is now settling down. The plant was designed using the latest concepts in an integrated plant layout and whilst breaking new boundaries in terms of throughput capacity on banana screens, has lent heavily on lessons learnt during previous plant designs.

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