Low cut SX10 spiral and Optima classifier combination: Optimizing a fine coal processing circuit

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Recent years have seen an increase in the use of low-cut spirals and classifiers in the South African fine coal processing industry. This is especially seen in wash plants that produces an export/low ash export product and a secondary thermal coal product for Eskom. It has been shown that when processing fine coal, each technology has its advantages and disadvantages.

This paper evaluates an approach of combining technologies in a fine coal processing circuit. An approach where, -2mm+0.15mm ROM coal was fed to the SX10 low-cut spiral as well as to an Optima Classifier™ was first evaluated. Secondly, a scenario was investigated where the Optima discard was fed to the SX10 low-cut spiral.

The results showed that the SX10 was able to produce a product with a CV and ash yield of 26.49 MJ/kg and 16.6% respectively. This is closely comparable with the Optima Classifier™ (OPC) product of 26.45 MJ/kg and 16.85% ash yield. However, the SX10 spiral was only able to achieve a 29.08% product yield. Seeing that the OPC had a product yield of 43.8%, it proved to be a superior rougher as compared to the SX10 spiral. The Optima discard had a CV of 12.78 MJ/kg and an ash of 51%. The SX10 spiral showed a considerable upgrade on the Optima discard and was able to produce an Eskom product at 21.7 MJ/kg and 29.1% ash, at a product yield of 45.3%. The Optima-SX10 combination showed great potential, delivering an overall product yield of 69.26%. An economic evaluation showed that this circuit has the potential of doubling the revenue for operations by producing a diversified product range for both export and local markets.

KEYWORDS: SX10 spirals, Optima classifiers, low specific gravity cut point, fine coal processing

Introduction

South Africa (SA) is one of the most significant producer, consumer, and exporter of coal in the world (de Korte, 2002; Eberhard, A., 2011). Unfortunately, mechanized mining methods and comminution has led to the increased production of fine coal. The -0.5mm material has been reported as being 15% of most South African ROM material (England et al., 2002). This value has been reported to have increased to about 30% in more recent years (Baloyi *et al*., 2019).

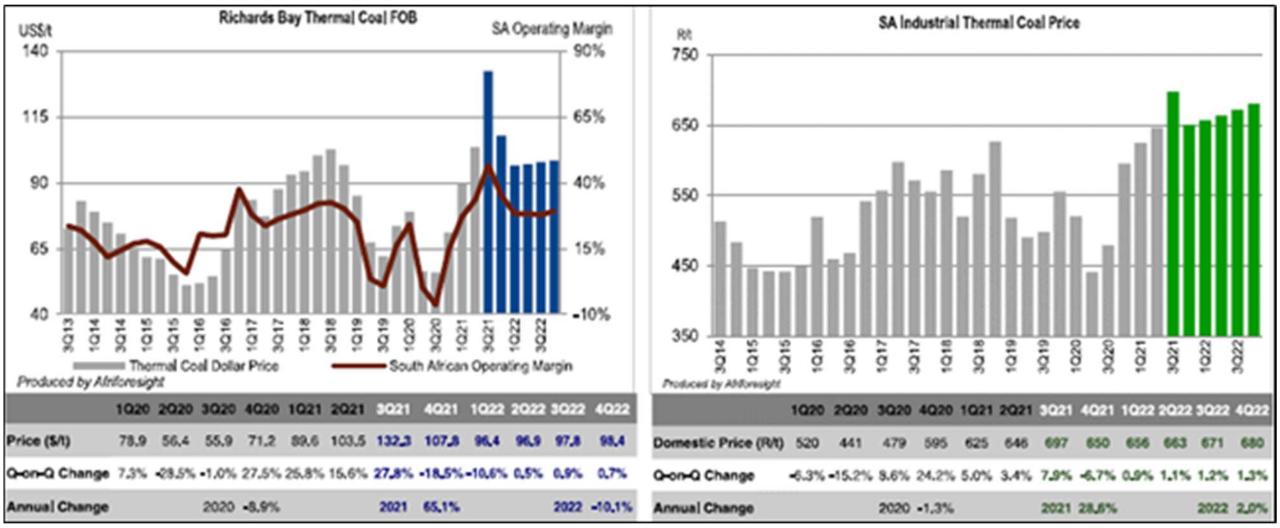
Seeing that the fine coal is of economic value, the beneficiation thereof has seen increasing attention in the South African coal market. The most common processes available for fine coal beneficiation are spirals, flotation, dense medium separation (DMS), water only cyclones, teeter beds and classifiers (Ramotsabi *et al.*, 2015). Spirals, teeter beds and classifiers are primarily used for cleaning coal in the intermediate size range of 100µm to 2000µm. These coal particles are neither large enough for heavy media separation and nor small enough for froth flotation (Kapur & Meloy, 1999).

The saleable coal produced in SA is supplied to four main markets which include the global export market, the domestic synfuels (Sasol) market, the domestic energy supply (Eskom), and the domestic heating and industrial use. These markets are reported to consume about 27%, 18%, 46% and 9 % of the saleable coal produced in south respectively (Steyn & Minnitt, 2010). The market has various product specifications in terms coal quality, thermal characteristics, and sizing. Figure 1 shows a summary of the various market's product specifications.

Table 1: Various coal product specifications (Steyn & Minnitt, 2010)

Parameter	Units	Eskom	Domestic	Export
Calorific Value	Mj/kg (NAR)	21-25	24.5-275.	27.5 (5850-6000 kcal/kg)
Total moisture	% (AR)	8-12	8-12	8-12
Ash	% (AR)	25-34	15-21	15
Volatile matter	% (AR)	20-30	23-30	20-22
Sulphur	% (AR)	0-2	0-1.5	0-1.0
Sizing	mm	0x40	0x6 6x25 25x40	0x50

The higher quality products such as export coal attracts higher premiums than domestic products such as Eskom coal. This can be seen in Figure 1, which shows the price per ton of coal for the various markets.



	1Q20	2Q20	3Q20	4Q20	1Q21	2Q21	3Q21	4Q21	1Q22	2Q22	3Q22	4Q22
Price ($/t)	78.9	56.4	55.9	71.2	89.6	103.5	132.3	107.8	96.4	96.9	97.8	98.4
Q-on-Q Change	7.3%	-28.5%	-1.0%	27.5%	25.8%	15.6%	27.8%	-18.5%	-10.6%	0.5%	0.9%	0.7%
Annual Change			2020	-8.9%			2021	65.1%			2022	-10.1%

	1Q20	2Q20	3Q20	4Q20	1Q21	2Q21	3Q21	4Q21	1Q22	2Q22	3Q22	4Q22
Domestic Price (R/t)	520	441	479	595	625	646	697	650	656	663	671	680
Q-on-Q Change	-6.3%	-15.2%	8.6%	24.2%	5.0%	3.4%	7.9%	-6.7%	0.9%	1.1%	1.2%	1.3%
Annual Change			2020	-1.3%			2021	28.6%			2022	2.0%

Figure 1: Richards Bay (RB1) and SA Industries Thermal Coal Prices (Afriforsight)

Coal for the export market is shown in dollars/ton and coal for the domestic market in rands/ton. For Q3 of 2021, the domestic products were trading at R697/ton while RB1 export product was trading at $132.3/ton, at the rate of exchange of R14.13 this amounts to R1870/ton. From the differences in prices above it can be seen that selling more of the export product can generate more revenue for operations. Therefore, flexibility within processing plants to be able cater for the different markets can provide operations with an opportunity to diversify their product offering and generate more revenue by selling multiple products.

This paper, therefore, focusses on the beneficiation of fine coal using the low cut SX10 spiral and the Optima Classifier (OPC). The aim of the study is to determine the best combined fine coal processing circuit to produce an export/low ash product and thermal coal as a secondary product for Eskom. This will be done by investigating the beneficiation performance of both the SX10 spiral and Optima Classifier in processing fine coal.

Literature Review

Beneficiation technologies

Market specifications and coal washability often dictates the beneficiation technologies used in fine coal preparation plants, worldwide. Due to this, coal preparation plants vary significantly in layout and the beneficiating technologies used in the plant (Luttrell *et al.*, 2014).

Where high coal quality products are required a technology with a lower SG cut point capability is required to achieve such a product. For these applications classifiers are usually the preferred choice over spirals. Classifier separators provide variable cut densities at decent yields, however if higher product qualities are targeted the discard from these technologies have been shown to still contain valuable coal.

Spirals separate valuable minerals from gangue on the basis of their density. Among the gravity separators, the spiral concentrator is one of the most efficient and simple unit operations (Das *et al.*, 2007). Traditional spirals are classified as high cut technologies with typical cut densities between 1.65 and 1.8. Recent developments in spirals have seen the introduction of low-cut spirals to the markets. Previous work done by Ramsaywok and Mathumbu (2017) showed that a low cut on the newly developed LC3 spiral, in the range of 1.45 to 1.55, is achievable. This was however achieved at lower throughputs, solid concentration than traditional spirals. The results also indicated that this is also comes at a lower mass yield. The implication is that more spirals will be required and an increase in footprint can be expected.

In another study, Arnold *et al.* (2019) showed that the Multotec SX10 low cut spiral achieved low cut densities in the range of 1.5 to 1.55. This was achieved at a throughput in the range of 2.5tph to 3tph, which is higher than other low-cut spirals. The SX10 spiral is a10 turn, 1000mm diameter spiral, equipped with 2 repulpers positioned at the 4th and 7th turn, making it a 3 stage in 1 ow-cut spiral. A picture of the SX10 is displayed in Figure 2.

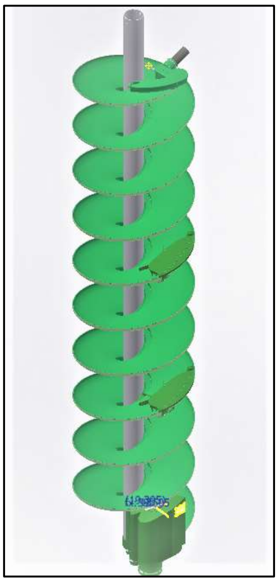


Figure 2: SX10 spiral

The SX10 has 2 offtakes that direct the discard into the auto reject center column. The offtakes are there to remove portions of the discard that has been separated from the working surface on the spiral. This increases the surface area available for separation and allows more material to be processed without excessively increasing particle crowding on the spiral. With more of the undesired material removed higher up the spiral, the reduced solids loading and solid concentration of the material lower down the length of the spiral creates a favorable environment for a low-cut product to be achievable. The offtakes are positioned before the repulpers. This ensure that once a portion of the discard is removed, while the material remaining on the spiral is mixed again by the repulper.

Because of its relative simplicity and high efficiency, spirals are widely used under a variety of circuit configurations for the processing of minerals and coal (Das *et al.*, 2007). Spirals are simple, low energy consuming devices with no mechanical moving parts. They are easy to operate and less sensitive to particle size than the classifiers. The capital cost is relatively low compared to other technologies and the operational costs are also minimal (Erasmus *et al.*, 2016).

Spirals are low maintenance, however regular washing and checking of blockages and process control is required to ensure that they are not overfed. They are usually neglected in the plant and get used as ladders. Deviation from ideal operating conditions can negatively impact the separation efficiency of spirals, resulting in a high cut point and lower product quality (Erasmus *et al.*, 2016).

Separation on a spiral is not only depended on the density of the particles but also on the size of the particles. The bigger particles are affected more than smaller particles. Therefore, gravity concentration efficiency increases with an increase in particle size. To ensure efficient separation desliming is required, slimes are particularly detrimental for coal since the slimes usually contain high ash content (Erasmus *et al.*, 2016).

Similar to spirals, classifiers form a very important part of the gravity separation technologies in fine coal and has been investigated widely in the fine coal beneficiation market (Kopparthi *et al.*, 2019). One of the most recent classifiers introduced to the fine coal processing market is the Optima Classifier™ (OPC). The Optima Classifier, developed by Gravitas Minerals, is a hindered settling classifier that separates material based on density. A schematic diagram of the Optima Classifier can be seen in Figure 3.

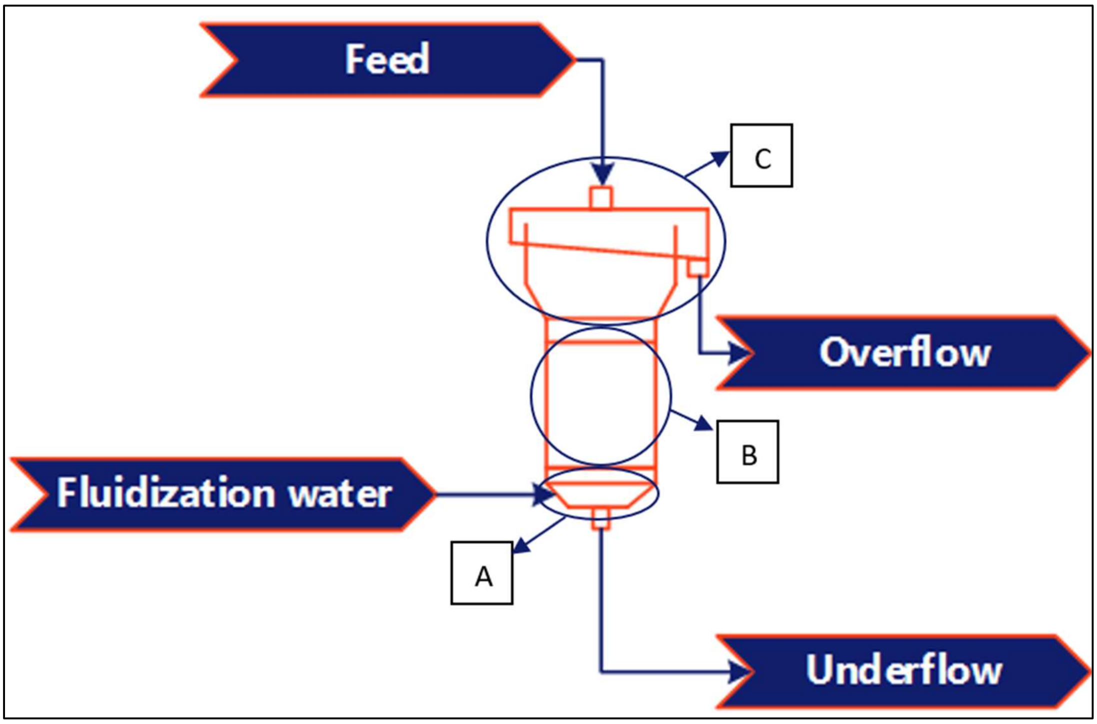


Figure 3: Schematic diagram of the Optima Classifier.

The OPC`s operating mechanism is based on the principles of fluidization and hindered settling. The water enters the bottom of the optima via the fluidization chamber [A] and is distributed through nozzles into the fluidised bed chamber [B]. The slurry is introduced from the top of the OPC into the fluidised bed chamber where denser particles settle to the bottom and less dense particles remain in suspension. The fluidization water will ensure that the less dense will particles continuously discharged through the overflow section of the OPC. The recover chamber [C] is designed to ensure a lower upward velocity, prohibiting material bypass. Should any heavy material be displaced to the recovery chamber, the reduced velocities allow the material to settle back into the fluidised bed chamber. This effect then creates a high concentration of fine, dense, material which acts as an autogenous dense media. The autogenous dense media aids with the separation as material less dense than the media will find difficulty in penetrating the media.

Pressure sensors are used in conjunction with a PLC and electric underflow valve to control the OPC. The PLC converts the pressure readings to a relative density. Once the desired bed density has been reached the underflow valve opens and discharges the heavy particles.

There are several advantages in using a classifier such as the OPC over processing equipment such as spirals, teetered bed separators and dense media cyclones, for beneficiating fine coal. The advantages include high throughout per unit area, robust operation, good separation efficiency and the ability to consistently produce a high-grade product (Kopparthi *et al.*, 2019; Modiga, *et al.*, 2019). There are, however, some limiting factors that negatively influences the efficiency of the OPC. One of these factors is top to bottom size ratio of the feed particles. The limit to the feed particle size ratio has been shown to be 1:8. A narrow particle size range is thus needed for optimal efficiency. In the case of beneficiating coal with a particle top size of 0.1mm this ratio is significantly lower (Iveson *et al.*, 2014).

Experimental

Two scenarios were investigated. Firstly, the low-cut spiral and the classifier were tested individually and secondly the Optima discard was fed to a low-cut spiral. Figure 4 [A] and [B] displays these two scenarios.

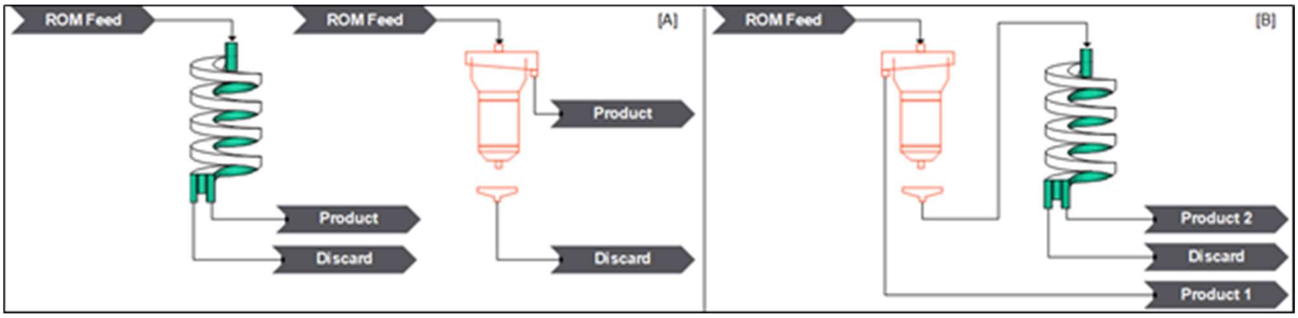


Figure 4: Experimental scenarios that was investigated

The performance results of the SX10 and OPC, as well as the two processing scenarios were compared to each other, using the same feed conditions.

Feed sample characterization

The ash yield and CV of the feed sample was analyzed for size fractions from 2mm to 0.15mm. The relationship between PSD, CV and ash yield of the feed sample is summarized in Table 2.

Table 2: Feed sample characterization

Feed size	Ash (%)	CV (MJ/kg)
-2+1mm	37.60	18.41
-1+0.85mm	35.40	19.50
-0.85+0.5mm	35.70	19.70
-0.5+0.3mm	38.00	19.12
-0.3+0.15mm	42.00	17.51
-0.15mm	59.60	11.04

From Table 2, the -0.15mm fraction displayed a very low CV and high ash yield. Seeing that both the OPC and SX10 are gravity separators, it is possible that the -0.15mm slimes would report to the product of the respective technologies. It was therefore necessary to remove this size fraction from the feed, to prevent it from lowering the quality of the OPC and SX10 product. The cumulative ash yield and CV of the -2mm+0.15mm feed sample is summarized in Table 3.

Table 3: -2mm+0.15mm feed sample characterisation

Feed	Ash (%)	CV (MJ/kg)	Mass (kg)	Mass %	Cumulative mass %	Cumulative ash (%)	Cumulative CV (MJ/kg)
-2+1mm	37.60	18.41	10.69	18.52	18.52	37.60	18.41
-1+0.85mm	35.40	19.50	3.66	6.35	24.87	37.04	18.69
-0.85+0.5mm	35.70	19.70	11.50	19.93	44.80	36.44	19.14
-0.5+0.3mm	38.00	19.12	13.03	22.57	67.37	36.96	19.13
-0.3+0.15mm	42.00	17.51	18.83	32.63	100.00	38.61	18.60
Total			57.7				

The cumulative ash and CV of the feed sample used in the experimental procedures was thus calculated to be 38.61% and 18.60 MJ/kg respectively.

Setup and procedure

Optima Classifier

The Optima Classifier™ is available in different sizes to provide the necessary throughput as demanded by the situation. The lab scale Optima Classifier™, OPC150, has a fluidization chamber with a diameter of 150mm. The experimental setup of the OPC150 is shown in Figure 5.

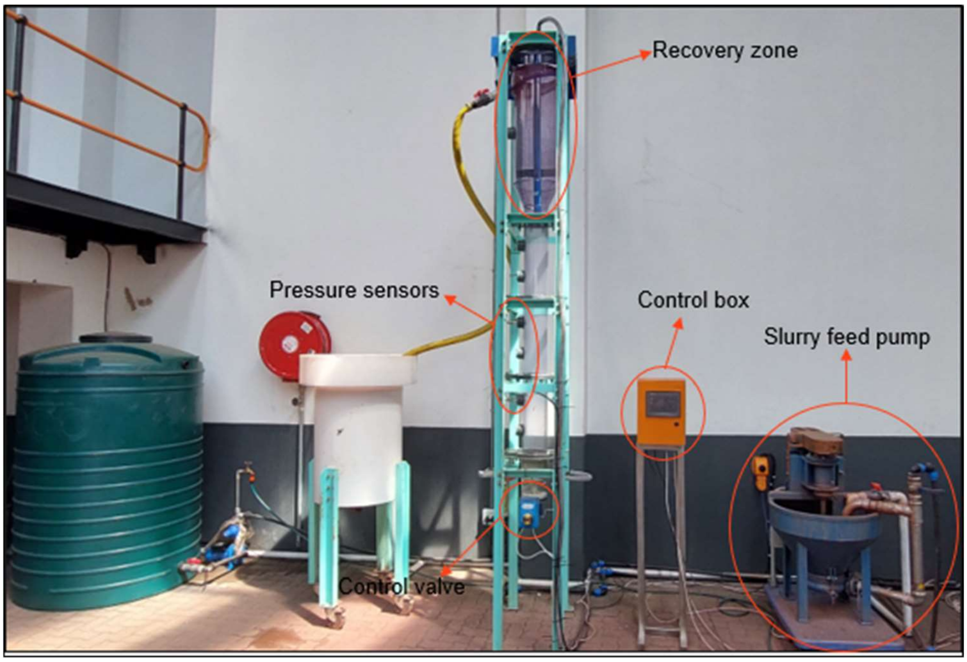


Figure 5: Optima experimental setup

For this experiment a slurry feed with ±15% solids were maintained at a feed rate of 1000-1300 l/h. The slurry was introduced via the blue pipe just below the recovery chamber, using a slurry feed pump. Fluidization water was introduced at the bottom of the OPC150 at a rate of 400l/h. In the fluidization zone pressure sensors were positioned at a hight of 500mm from each other. A relative density set point (RDSP) of 1.4 was set using the control box. Once the RDSP was reached the underflow valve discharged until the relative density was below the RDSP.

The overflow of the OPC150 is discharged into a settling tank, where the overflow of the settling tank was recycled back to the slurry feed pump. Both the underflow of the OPC150 and the settling tank was collected in buckets, dried and sent for analyses.

SX10 Spiral

The SX10 spiral was equipped with a mouth organ to collect samples across the spiral trough as shown in Figure 6.

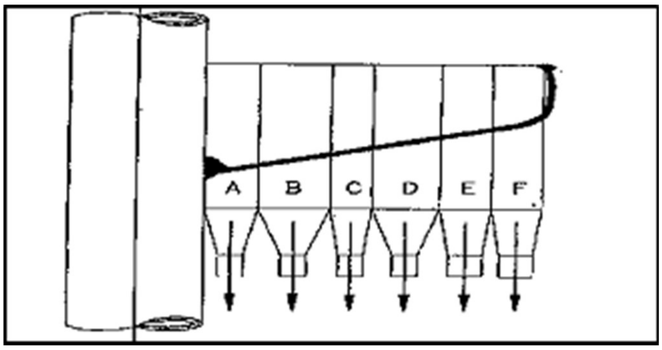


Figure 6: Mouth organ product box for test units

In addition to the samples collected across the trough, a reject sample also collected from the center column outlet. Table 4 shows the operational parameters of the SX10 spiral.

Table 4: Operating range for the SX10 spiral

Coal spiral			Primary/Secondary duty
Solids dry tonnage	tph	Max	4.0
	tph	Min	2.0
Volumetric flow rate	m^3/hr	Max	13.5
	m^3/hr	Min	7.6
Particle size	µm	Max	2000
	µm	Min	106
Feed % solids	%	Max	40
	%	Min	25

The SX10 was tested at 35% solid concentration and 3tph. The product samples were analyzed for ash and calorific value (CV).

Results and *Discussion*

Optima Classifier

At the operating conditions as describe in the experimental of the OPC was able to produce a product with a CV and ash of 26.45 MJ/kg and 16.85% respectively. A schematic of the OPC experimental results can be seen in Figure 7.

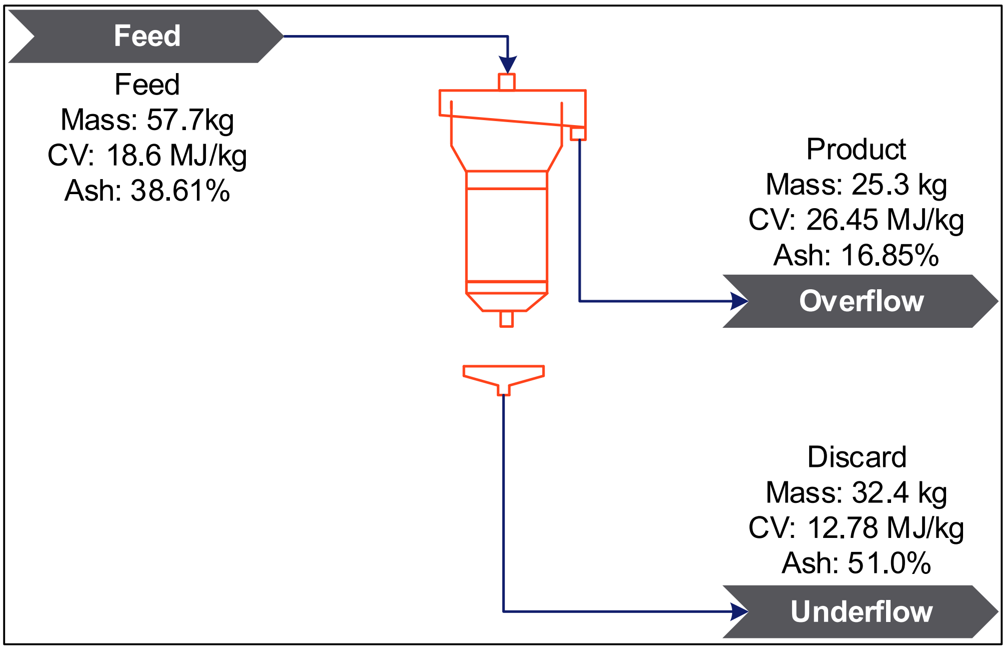


Figure 7: Summary of the OPC experimental results

From Table 3 it was concluded that the deslimed feed had a CV of 18.60 MJ/kg and an ash yield of 38.61%. An upgrade of 7.85 MJ/kg and 21.76% was thus seen in CV and ash yield respectively. From as Figure 7 the product mass yield was calculated to be 43.8%. The capability of the OPC to produce a product of higher quality is displayed in Figure 8, which shows the product CV and ash yield as a function of overall product yield.

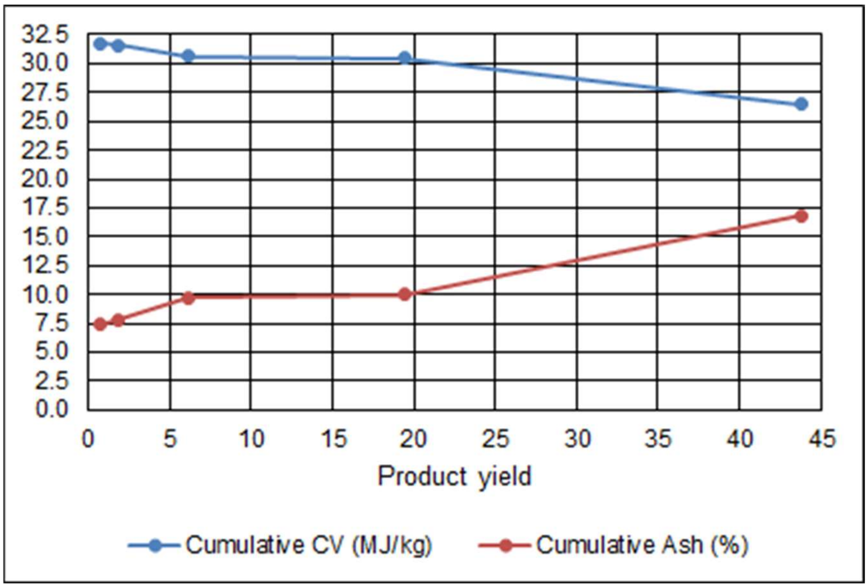


Figure 8: OPC CV and ash vs product yield

It can be seen that a reduction in the product ash yield and increase in product CV is achievable, with a reduced product yield. Based on this the OPC is able to produce a RB1 product with an ash yield of <15% and a CV of 27.81 MJ/kg at an overall product yield of approximately 35.5%. Seeing that fine coal readily retains moisture that negatively influences the CV of the product, it is important to produce a product that has a CV (ad) above the minimum requirements (de Korte, 2010). The NAR CV of the 27.81 MJ/kg product was calculated to be 5851.01 kcal/kg for a moisture between 10 and 15%.

SX10 spiral

Effect of slimes on the SX10 performance

The effect of slimes on the performance of the SX 10 spiral was investigated to determine the magnitude to which it influences the SX10`s efficiency. The results of this investigation are shown in Figure 9.

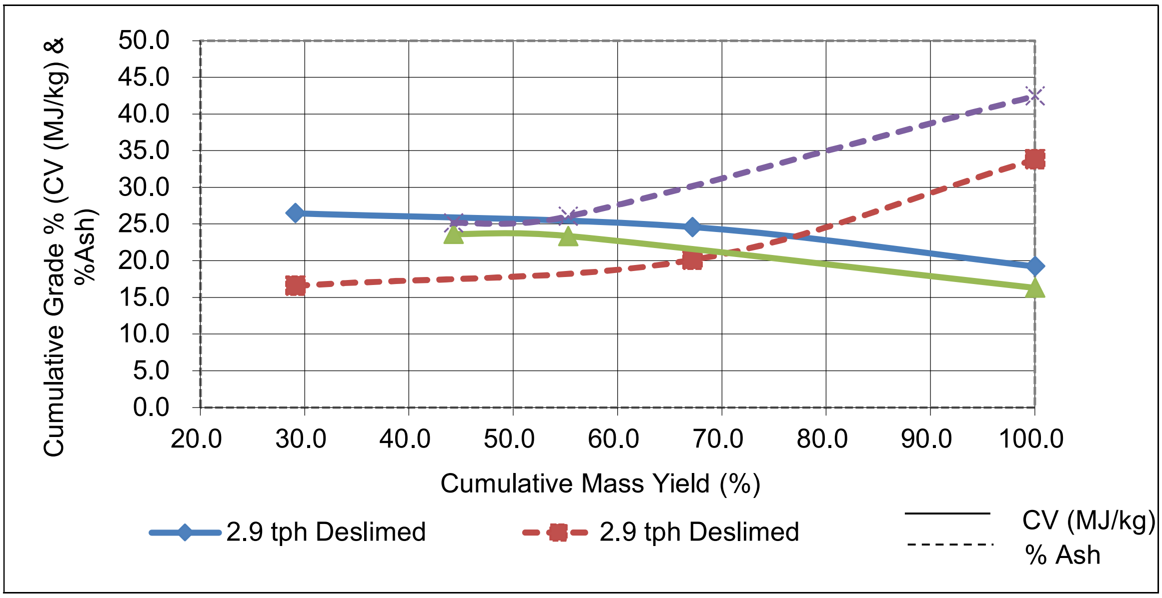


Figure 9: Effect of Slimes on the SX10 Spiral

With slimes present in the feed, upgrade from a CV of 16.32 to 23.66 MJ/kg was achieved. The ash was downgraded from 42.45% in the feed to 25.15% in the product. This was achieved at 44.24% mass yield. When deslimed, the feed was upgraded from a CV of 19.24 to 26.49 MJ/kg, the ash was downgraded from 33.81% in the feed to 16.6% in the product. This was achieved at 29.08 % mass yield. A complete summary of the 2.9 tph experiment with and without slimes in Table 5 and 6.

Table 5: SX10 Performance at 2.9tph without Slimes

Sample Description	Distribution	Cumulative Distribution	CV	Cumulative CV	Ash	Cumulative Ash
Product	29.08	29.08	26.49	26.49	16.60	16.60
Middlings	38.06	67.15	23.15	24.60	22.80	20.11
Discard	32.85	100.00	8.30	19.24	61.80	33.81

Table 6: SX10 Performance at 2.9tph with Slimes

Sample Description	Distribution	Cumulative Distribution	CV	Cumulative CV	Ash	Cumulative Ash
Product	44.24	44.24	23.66	23.66	25.15	25.15
Middlings	11.02	55.26	22.23	23.38	29.67	26.05
Discard	44.74	100.00	7.61	16.32	62.71	42.45

It is clear that removing the slimes enhances the final product grade and it therefore a necessity.

Effect of feed rate on the SX10 performance

The effect of the feed rate on the performance of the SX was investigated. Figure 8 displays the results of this investigation.

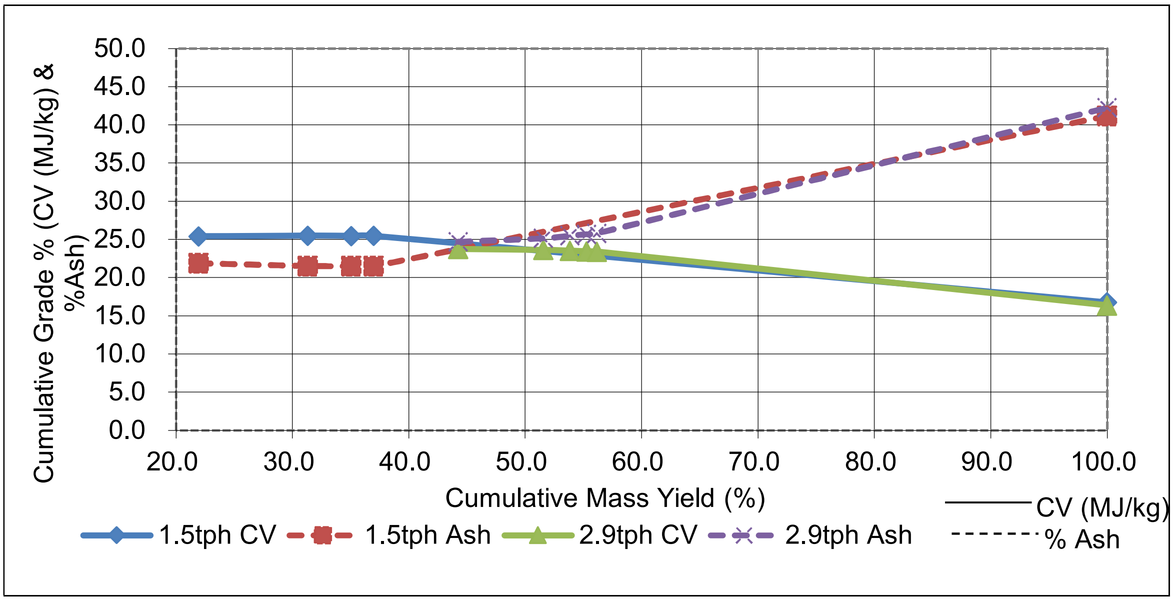


Figure 10: Effect of feed rate on the SX10 spiral

At a feed rate of 1.5tph, the feed was upgraded from a CV of 16.4 to 25.15 MJ/kg, the ash was downgraded from 42.30% in the feed to 21.19% in the product. This was achieved at 21.19% mass yield. At a higher feed rate of 2.9tph, the feed was upgraded from a CV of 16.4 to 24.7 MJ/kg, while the ash was downgraded from 42.3% in the feed to 24.7% in the product. This was achieved at 44.4 % mass yield. At mass yields above 44.5% both tests showed similar ash yields. The difference in feed rate did not result in a significant difference in the upgrade, however it should be noted that at lower feed rates the splitters should be opened wider to achieve similar a performance as at higher feed rate.

OPC and SX10 combination

From the SX10 spiral discussion, it was seen that the SX10 was able to produce a product with a CV and ash yield of 26.49 MJ/kg and 16.6% respectively. This is closely comparable with the OPC product of 26.45 MJ/kg and 18.85% ash yield. However, the SX10 spiral was only able to achieve a 29.08% product yield. Seeing that the OPC had a product yield of 43.8%, it proved to be a superior rougher as compared to the SX10 spiral.

Based on this, a scenario was investigated where the OPC was used as a rougher to produce export product and the SX10 was used as a scavenger to produce Eskom product. The overflow of the OPC was regarded as final product and the underflow of the OPC was scavenged using the SX10. Figure 11 shows the grade yield relationship of the Optima discard material on the SX10 spiral.

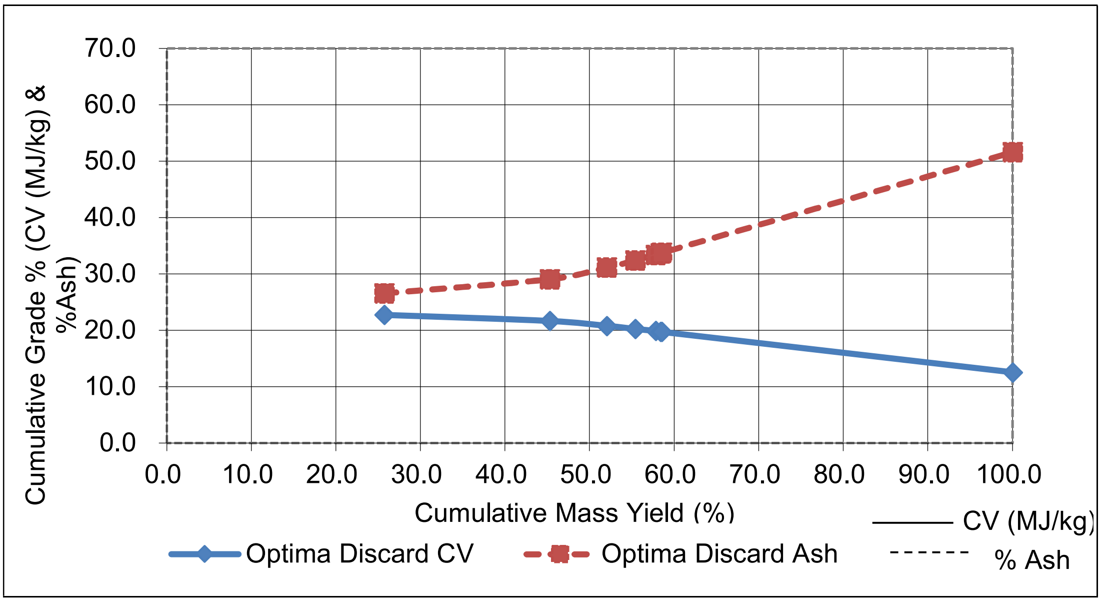


Figure 11: Optima Discard grade vs mass yield for the SX10

The OPC discard was upgraded from a CV of 12.6 to 22.7 MJ/kg, the ash was downgraded from 51.6% in the feed to 26.4% in the product. This was achieved at 25.70% mass yield. A summary of the OPC discard run on the SX10 is shown in Table 7.

Table 7: Summary: Optima Discard

Sample Description	Distribution	Cumulative Distribution	CV	Cumulative CV	Ash	Cumulative Ash
Product	25.72	25.72	22.76	22.76	26.40	26.40
Middlings	29.67	55.39	18.10	20.26	37.40	32.29
Discard	44.61	100.00	3.10	12.61	75.70	51.66

The data in Table 7 shows that it is feasible to achieve a product at 21.7 MJ/kg, with a 29.1% ash yield, at 45.3% mass yield. The results of OPC discard SX10 experiment was used in conjunction with the OPC results to calculate the results of the OPC-SX10 combination and is summarized in Figure 12.

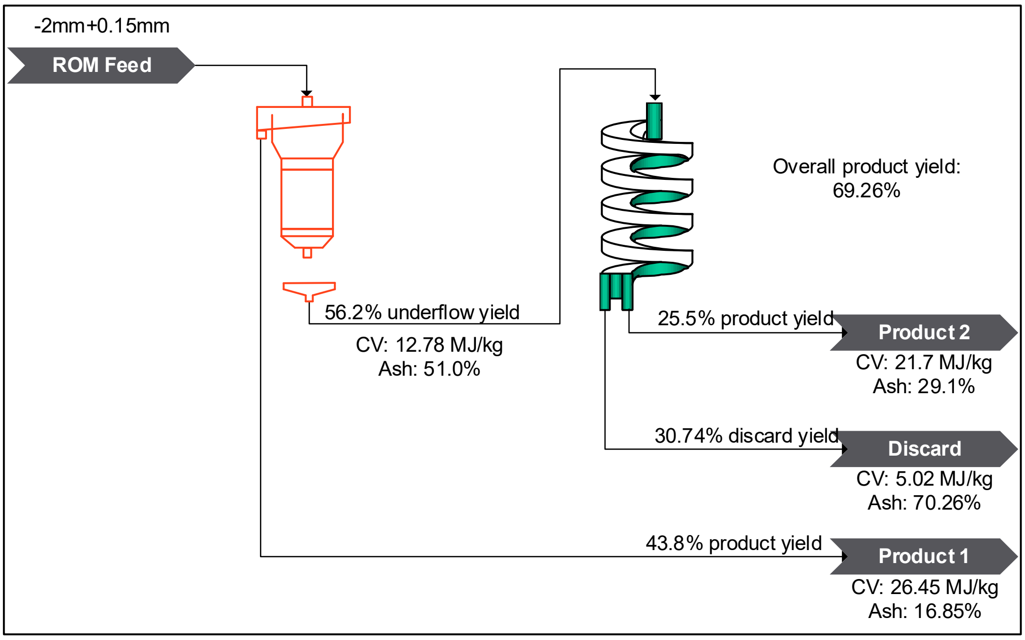


Figure 12: OPC-SX10 spiral combination

The OPC-SX10 circuit showed a combined product yield of 69.26%, with a discard yield of 30.74%. The discard CV was found to be 5.02 MJ/kg and the ash of 70.26%.

Application

From the experimental result it was seen that the OPC-SX10 combination shows great promise. It is therefore necessary to evaluate the economic feasibility of this combination to determine large-scale applicability. The parameters of the economic analysis are summarized in Table 8.

Table 8: Economic evaluation parameter of OPC-SX10 combination for a 40tph modular plant

Description	Measure	Value
Throughput	Tons per hour	40
Operating time	Hours per month	500
Feed PSD	mm	-2+0.15
Slimes in feed	%	20
Product 1 selling price	Rand per ton	1870
Product 2 selling price	Rand per ton	697

A PFD of the proposed OPC-SX10 circuit is displayed in Figure 13.

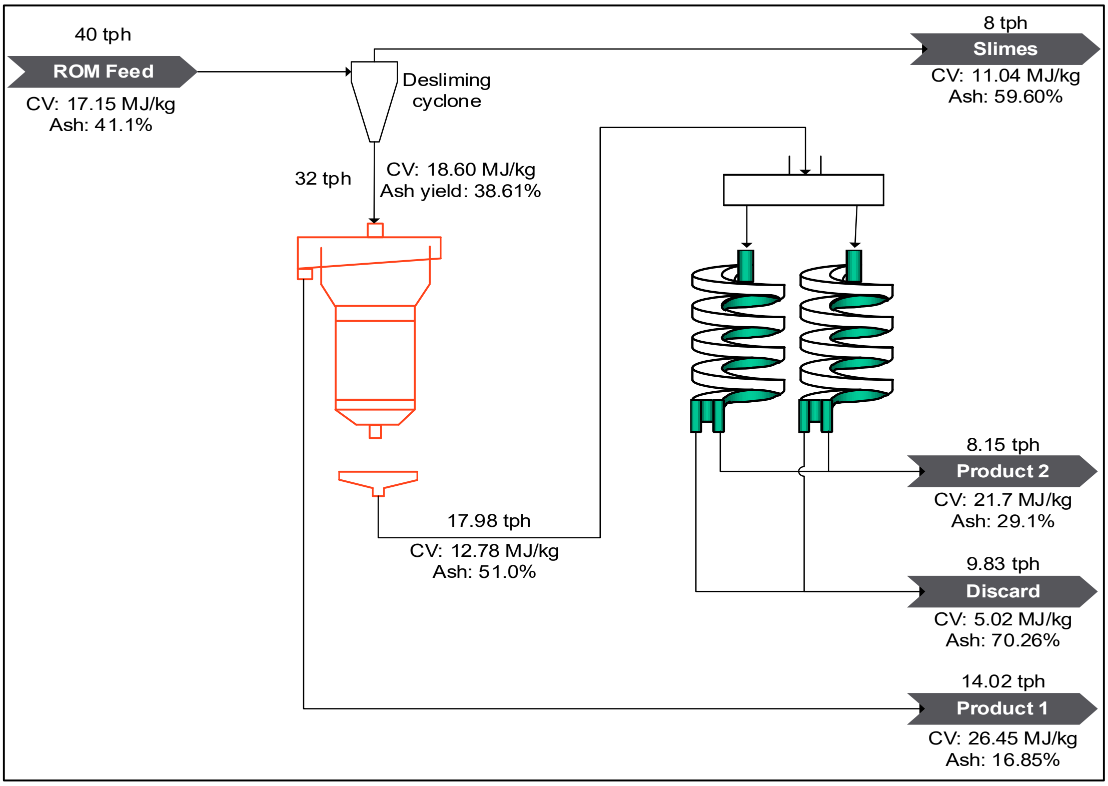


Figure 13: OPC and SX10 Circuit

Based on the production of 14.02 ton per hour of product 1 and 8.15 tons per hour of product 2. Selling product 1 as RB1 @ R1870/ton will provide a revenue of around R13.1M, selling product 2 as Eskom product @ R697/ton will provide a revenue of R2.8M. This provides a total revenue of R15.9M for both products, if only one product was produced say only Eskom the total revenue would be only R7.7M. As can be seen from the illustration above, diversifying the product range provides operations with an opportunity to increase their revenue.

Conclusion

The results showed that the SX10 was able to produce a product with a CV and ash yield of 26.49 MJ/kg and 16.6% respectively. This is closely comparable with the OPC product of 26.45 MJ/kg and 16.85% ash. However, the SX10 spiral was only able to achieve a 29.08% product yield. Seeing that the OPC had a product yield of 43.8%, it proved to be a superior rougher as compared to the SX10 spiral

From the experimental results it was concluded that the OPC was best suited to be used as a rougher as it produced a product with the same specifications as the SX10 spiral, but at a 14.7% higher yield. The OPC produced a product with a CV of 26.45 MJ/kg and ash % of 16.85% from a feed with a CV of 18.6 MJ/kg and ash of 38.61%. The SX10 spiral was able to produce an Eskom product with a CV of 21.7MJ/kg and an ash of 29.1% from the OPC discard stream at a 45.3% yield. The OPC-SX10 combination showed a combined product yield of 69.26% producing a final discard with a CV of 5.02 MJ/kg and an ash of 70.26%. An economic evaluation showed that this circuit has the potential of doubling the revenue for operations by producing a diversified product range for both export and local markets.

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