Evaluating the application of the Optima® classifier as a secondary beneficiation stage at the Phola Coal Processing Plant

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Abstract. South Africa's coal mining operations frequently produce fine coal which is usually discarded due to the high costs of handling. Studies have shown that these fines possess acceptable market calorific values and low ash content. Processes have been widely developed to convert these fines into a marketable product to blend with coarse washed coal to improve overall yields. Phola Coal Processing Plant makes use of triple start spirals to produce three streams of coal from the feed namely: product, middlings and discard. The spiral product is added primarily to the main DMS secondary product and opportunistically to the primary product depending on the quality, while the spiral discard and middlings are rejected. The spiral product contributes 5.2 % of the overall secondary product yield as a percentage of the head feed. Currently, the spiral material does not satisfy the primary product specification, and the goal of this test work was to ascertain whether the spiral product can be upgraded using the Optima® Classifier 500 pilot unit (OPC) in a second stage beneficiation to meet the primary product specification. The test work was based on upgrading the spiral feed and a combination of spiral product & middlings to primary product. The results showed that when desliming the -0.15 mm material in the final product, the OPC was able to achieve the necessary upgrade to meet the export product specification at an overall yield of 2.8 %.

1. Introduction and background

Coal is one of South Africa's most plentiful and valuable resource. Coal is processed to meet a range of market demands and majority of the export coal produced is transported by rail. The growth in low-grade export volumes is constrained by South Africa's limited rail capacity, which is primarily impacted by derailments, an unreliable rail network, and lack of resources [1–4]. This challenge is further intensified by increased production yields and saleable tonnages of low-grade exports, which in turn demand additional rail capacity [3]. Export coal is classified as RB1 and RB2 (RB = Richards Bay), requiring a minimum net calorific value of 6,000 kcal/kg with cut off CV`s of 5,850 and 5,700 kcal/kg respectively.

This specification necessitates the raw coal to be processed at a low relative density to meet the required export standards [5]. In most coal beneficiation plants, a two-stage dense medium processing strategy is used. In the first stage, run of mine coal is processed to produce an export-grade product, and in the second stage, rejects from the first stage are reprocessed at a higher relative density to produce thermal coal for the domestic market [6]. This processing strategy employs the use of a desliming screen prior to DMS to improve efficiencies within the circuit. The desliming screen typically removes the fine, -1.00 mm fraction, from the run of mine which was traditionally discarded or processed through gravity separators [7].

The mechanization of mining operations has contributed to a significant increase in fine coal production with recent research showing that the proportion of fines reporting to spiral circuits have increased up to 30 % [8–10]. This necessitates the need to process the fines to a saleable product. However, traditional beneficiation methods face challenges in efficiently upgrading these fines. Fine particles tend to report to the product stream due to their lower settling rates, which leads to dilution effects, suppressing the overall calorific value [11] . To mitigate the negative impact of fine particle retention on separation efficiency, innovative technologies are being developed to convert these fines into a marketable product, thereby improving overall plant yield and revenue generation [7]. Recovering these fines helps mitigate environmental concerns and reduce the need for land to dispose of mine waste. Gravity-based separation methods, such as spirals and classifiers, have been widely adopted for managing fine coal within the size range of -1.50+0.10 mm. Research by Wills and Finch [11] highlights that pre-treatment with spirals enhances gravity separation by reducing misplaced fines and improving product selectivity. Similarly, it was found that multi-stage gravity separation can improve CV by up to 2.5 MJ/kg through enhanced fine coal rejection, aligning with observed trends in beneficiation performance [12].

Phola Coal Processing Plant processes run-of-mine (ROM) material at a total head feed rate of 2,360 t/h, through a single-pass, double-stage system to produce both primary (high grade export) and secondary (low grade export) products. The fine coal circuit employs spiral concentrators designed for a nominal size fraction of -0.63+0.212 mm, accounting for 8 % of the total head feed (190 t/h). It is therefore critical to beneficiate this stream to maximise the recovery of the overall plant. The quality distribution of the spiral feed is illustrated in Figure 1, with CV values ranging from 12.51 to 27.64 MJ/kg (all calorific value data are reported on an air-dried basis (ADB), unless otherwise stated)

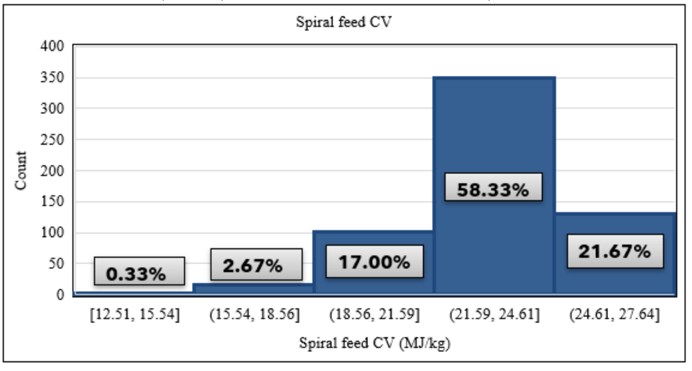

Fig. 1. Spiral feed CV distribution

The data indicates that 58.3 % of the time, the spiral feed falls within the range of 21.59 to 24.61 MJ/kg. Given that the plant aims for a middling's quality of 21.50 MJ/kg, this feed already meets the middlings classification but undergoes further processing to eliminate analytes such as sulphur. Figure 2 presents the quality distribution of the spiral product ranging from 18.66 to 28.61 MJ/kg.

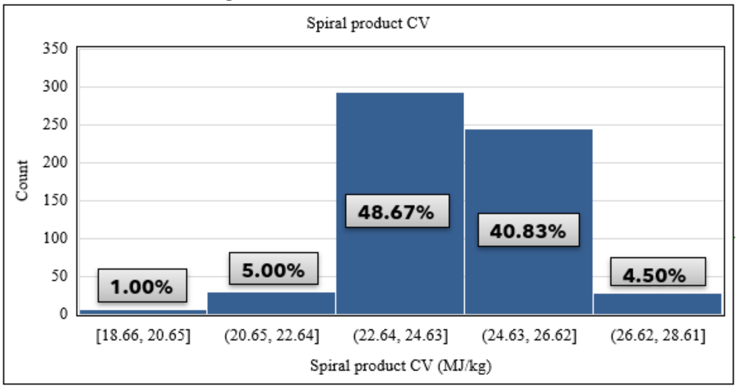

Fig. 2. Spiral product CV distribution

The data indicates that 48.7 % of the time, the product is between 22.64 and 24.63 MJ/kg. This product does not meet the plant's export quality product specification of 27.20 MJ/kg (minimum 26.80 MJ/kg) and is instead combined with the coarse middling's product from the DMS plant. Previous studies have indicated that while effective pre-treatment methods, such as desliming and classification before spirals or classifiers, can improve separation efficiency, they do not enhance product quality.

2. Fines beneficiation technologies

It has been observed that fine coal (2.0–0.15 mm) experiences a high misplacement rate because it to too fine for dense media cyclones and too coarse for froth flotation [13]. To efficiently process fine coal, various separation devices such as spirals [7,14,15], multi-gravity separators [16,17], classifiers [12,13,18], and teetered bed separators [19–21] have been adopted. At Phola Coal Processing Plant, spirals are primarily used for fine coal beneficiation due to their operational simplicity and ability to handle large throughputs.

2.1 Spirals

Spiral concentrators have become widely used for coal processing within the size range of -1.50+0.10 mm due to their ability to separate coal based on differences in particle density and size [14]. Spirals offer several advantages, including their effectiveness in separating coal by particle size and density, simple design with low maintenance needs and rely on gravity and centrifugal force, which minimizes the need for chemicals or complex processing [14]. Cut densities in spiral circuits typically range between 1.7 and 2.1 RD [22]. However, this fraction generally contains higher ash content, necessitating the need for effective desliming before beneficiation [14]. Test work conducted on the LC3 spiral demonstrated improved separation efficiency at lower cut densities (1.40–1.55 RD), achieving a better balance between recovery and product quality [23]. To achieve a high-grade RB1 product with a CV of 6,000 kcal/kg NAR, spirals require precise cut points at relative densities between 1.30 and 1.50 g/cm³ [3]. However, achieving such low-cut points consistently is operationally challenging without auxiliary classification or multi-stage treatment [3,23]. Due to limitations in separation efficiency, spirals alone often fail to achieve these precise cuts, leading to the need for additional processing stages. The inability of spirals to meet strict separation targets at Phola Coal Processing Plant has prompted the use of classifiers as a technology to enhance fine coal beneficiation.

2.2 Classifiers

Hindered settling devices, such as the reflux classifier, have been developed to enable effective separation at lower relative densities [3]. One of the latest innovations in the fine coal processing industry is the Optima® Classifier (OPC). Developed by Gravitas Minerals, the OPC operates based on the principles of fluidization and hindered settling. The OPC is designed to enhance separation efficiency by selectively removing misplaced fine coal particles while maintaining a high-quality product [24]. The Optima® Classifier consists of 3 main chambers. A fluidization chamber where water enters through the base of the unit and is evenly distributed through nozzles. A settling chamber where a stable fluidized bed is created, and a recovery chamber where an autogenous dense media is formed and misplaced particles are recovered [24]. A schematic of the OPC can be seen in Figure 3.

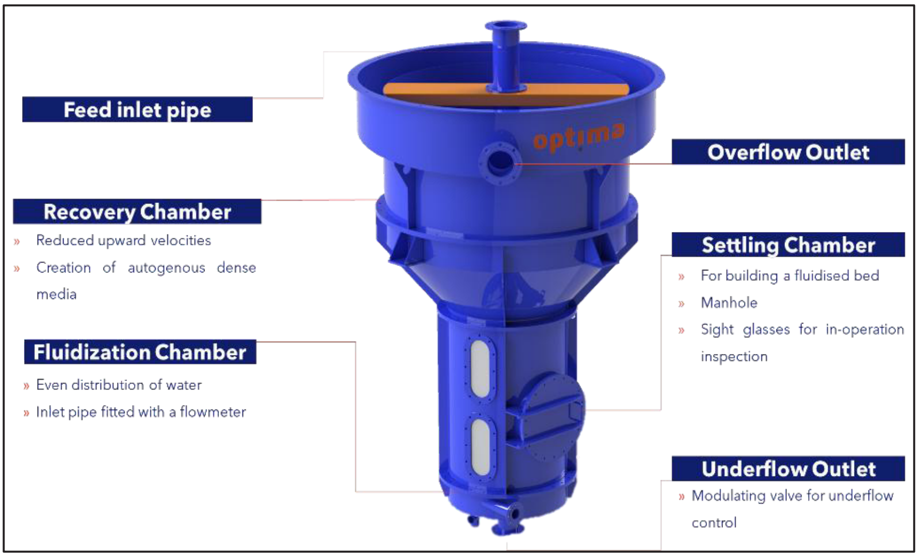

Fig. 3. Schematic representation of the Optima® Classifier, illustrating its main chambers.

The feed inlet pipe extends down to the conical section of the recovery chamber. Denser particles settle to the bottom of the settling chamber, while less dense particles remain suspended before being discharged through the overflow in the recovery chamber using up current water. The key advantages of the OPC include high throughput, consistent product grade, low footprint, and improved separation efficiency [24]. Recent studies have demonstrated the OPC's ability to upgrade spiral product CV from 21.50 to RB1 export quality, reducing ash content to below 18.0 % [25]. It has been demonstrated through pilot-scale trials that classifiers using hindered settling, such as the Reflux Classifier, can significantly improve fine coal beneficiation by achieving sharper cut points and upgrading coal quality. These findings support the potential of similar fluidization-based devices like the Optima® Classifier [12]. By integrating the OPC into existing spiral circuits, beneficiation plants can achieve higher-value coal products while minimizing yield losses. This study investigates the potential use of the Optima® Classifier to produce an RB1-grade coal product at Phola by: upgrading the spiral feed to meet RB1 primary product specifications, upgrading the existing spiral product and middlings, and evaluating overall yield contributions to the plant.

3. Methods

3.1 The test set up

Cyclone underflow deslimed at 0.15 mm, was used in conducting this test campaign. Two scenarios of feed to the OPC were investigated on as shown in Figure 4.

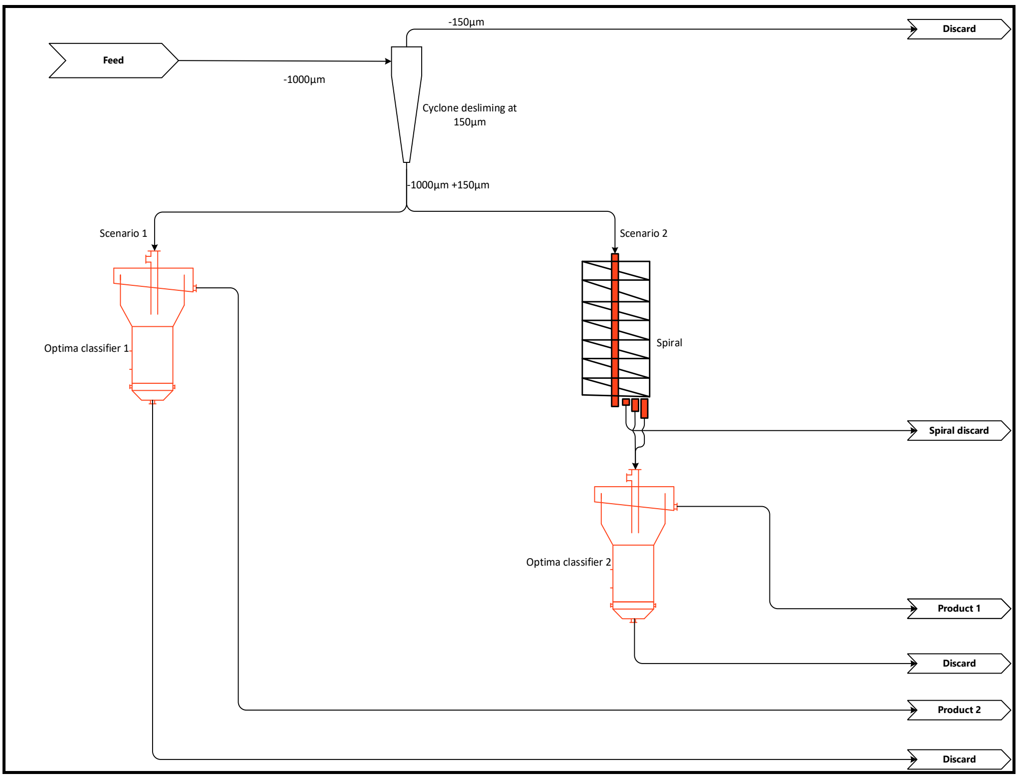

Fig. 4. Experimental set-up.

From Figure 4, Scenario 1 depicts that the cyclone underflow was fed to the OPC. In Scenario 2, the cyclone underflow was fed to the spirals, and the spiral product + middlings was fed to the OPC. For this pilot test work, the OPC500, as shown in Figure 5, was used.

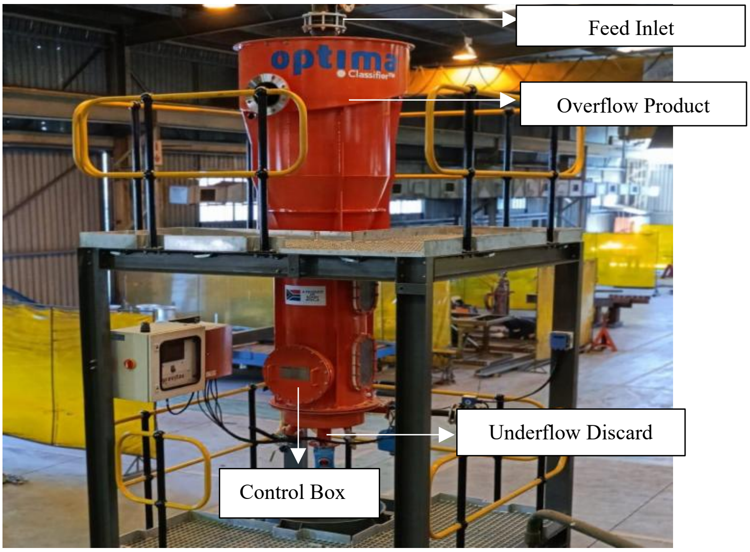

Fig. 5. Optima® Classifier (OPC500).

With the Optima Classifier set up, the feed rate of the OPC was kept constant at 9–11 m³/h, passing through the feed inlet. The slurry operating density was maintained at 1200 kg/m³, with a fluidization rate of 2.6–2.9 m³/h set and controlled via the control box.

3.2 The Feed

Table 1 summarizes the key differences of the two feed characteristic sources in the scenarios to the OPC in as cumulative ash %, cumulative CV and the % passing 0.15 mm.

Table 1. OPC feed summary.

	Scenario 1	Scenario 2
OPC Feed Stream	Cyclone U/F	Spiral product + middlings
Ash (%)	24.8	19.7
CV (MJ/kg)	21.31	23.63
Passing 0.15 mm (%)	27	18

Table 1 clearly indicates the capability of the spirals to upgrade the cyclone underflow at a head ash of 24.8 % and CV of 21.31 MJ/kg to 19.7 % ash and 23.63 MJ/kg. However, this also demonstrates the inability of the spiral to reach the required product specifications. Another key difference in the feed of the two scenarios is the difference in the presence of slimes. These slimes as discussed in the introduction and background will report to the product produced by the OPC.

4. Results and discussion

4.1 Scenario 1: Cyclone U/F as OPC feed

The relationship between particle size and calorific value (CV) of the feed, product and discard of the OPC is illustrated in Figure 6.

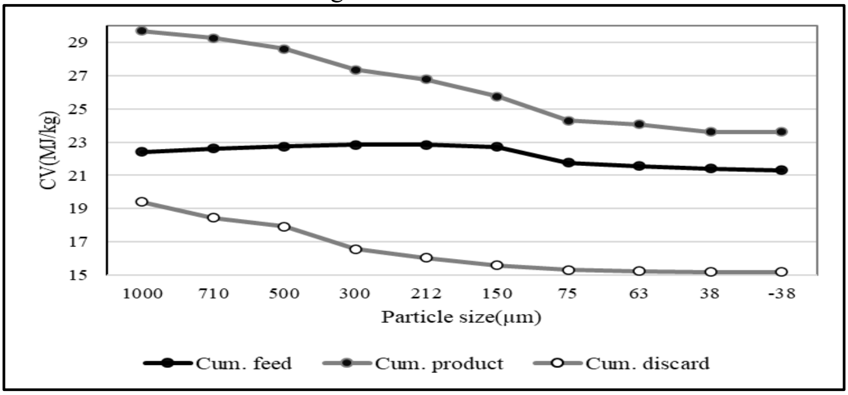

Fig. 6. Cumulative CV of the feed, product, and discard for Scenario 1 across different particle sizes

Figure 6 shows that the feed material exhibited a cumulative CV of 21.31 MJ/kg, which was upgraded to a cumulative CV of 23.65 MJ/kg. The CV showed highlights of reaching 29.68 MJ/kg at 1.00 mm and decreasing to a cumulative 26.27 MJ/kg at 0.212 mm before ultimately declining to 23.63 MJ/kg in the finest fractions. Cumulatively the OPC showed similar upgrade to the spiral, which showcases the impact of inefficient desliming. The key difference between the OPC and the spiral is shown in Figure 7.

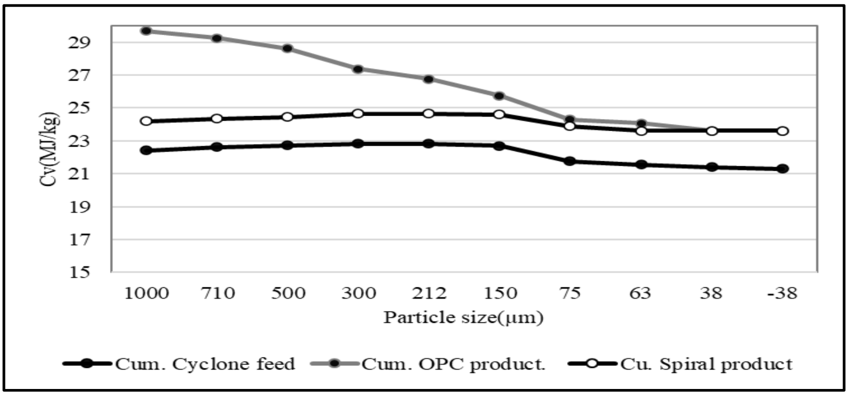

Fig. 7. Cumulative CV of the feed from Cyclone, OPC product as Scenario 1 and Spiral product before feed into the OPC across different particle sizes.

Figure 7 shows that the OPC and spirals reached the same cumulative product grade of approximately 23.50 MJ/kg. However, if the performance is evaluated per size fraction, the spiral product CV was 24.65 MJ/kg in the -1.5+0.212 mm range. Unlike the spiral, the OPC product CV was found to be approximately 27.00 MJ/kg within the same size range. These findings conclude that although the OPC did not meet the overall upgrade specification from the cyclone underflow, it does show capability of achieving this specification if upfront desliming is adequate. It was therefore necessary to investigate the presence of less slimes in the OPC feed, leading to Scenario 2 where spiral product + middlings was fed to the OPC with 18 % passing 0.15 mm as opposed to the cyclone underflow that showed 27 % passing 0.15 mm.

4.2 Scenario 2: Spiral product + middlings as OPC Feed

The cumulative calorific value trends for the OPC feed (spiral product + middlings), product and discard in Scenario 2 is presented in Figure 8.

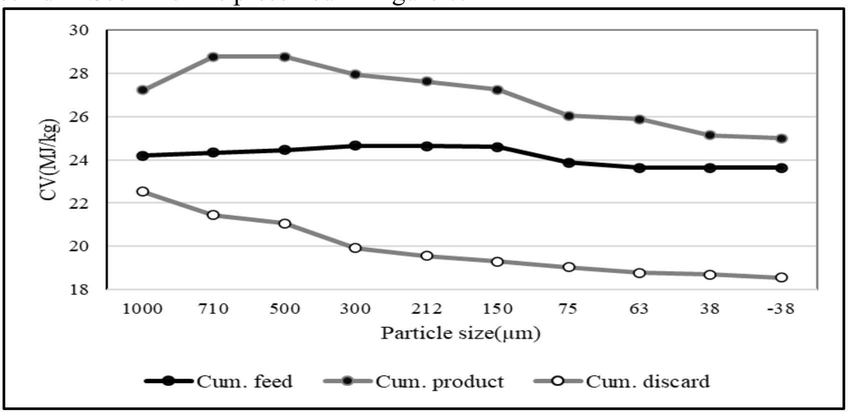

Fig. 8. Cumulative calorific value (CV) of the feed, product, and discard for Scenario 2 across different particle sizes.

The feed material in Scenario 2 had an initial CV of 23.65 MJ/kg and was upgraded to 24.99 MJ/kg cumulatively. The impact of using the spirals to pre-wash the fines is clearly seen in the shift in quality by size of the OPC product. In Scenario 1, the target 27.20 MJ/kg product was nearly reached in the -1.5+0.212 mm range. In Scenario 2, the required product was comfortably reached in the -1.5+0.15 mm range with a CV of 27.63 MJ/kg. These findings align with Wills and Finch [11], who highlighted that spiral pre-treatment enhances gravity separation by reducing misplaced fines and improving product selectivity. Similarly, previous research observed comparable trends, reinforcing the effectiveness of spiral pre-treatment in improving beneficiation outcomes [12]. The findings of Scenario 2 corroborate that of Scenario 1 where it is clearly seen that the OPC can affect low cut points and produce a high-quality export product. However, this is only achievable if the upfront desliming circuit is effective in removing the slime contaminants. Given that calorific value is strongly influenced by both moisture and inert mineral matter, the removal of fine, high-moisture fractions through advanced desliming is critical to maximizing product quality. The results of Scenario 2 demonstrate that when the feed to the Optima® Classifier contains a reduced percentage of slimes (<0.15 mm), the classifier can achieve export-grade CV levels within key size fractions. This highlights the importance of effective upstream desliming. Furthermore, incorporating product desliming has been shown to reduce moisture-laden fines and ash-forming inerts, leading to improved CV stability, enhanced blending flexibility, and better handling properties [13].

4.3 Comparison of Scenario 1 and 2 products

By comparing Scenario 1 and Scenario 2, the impact on overall plant yield and performance can be assessed. The difference in product CV and ash is shown in Figure 9.

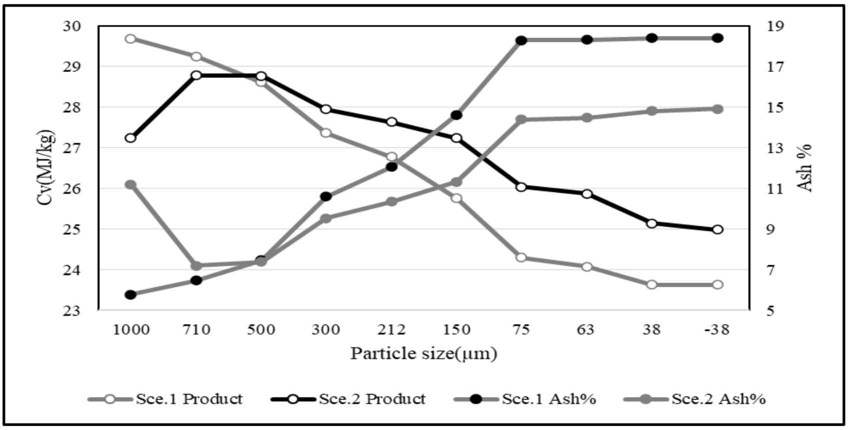

Fig. 9. Overall product calorific value (CV) and ash content comparison between Scenario 1 and Scenario 2.

In Scenario 1, the feed contained a higher proportion of slimes than in Scenario 2, where 81.7 % of the material was retained above 0.15 mm compared to 72.8 % in the direct OPC feed. While this represents an improvement, the presence of fine fractions remained important, affecting both the final product quality and the overall performance of the OPC. The final product CV in Scenario 2 was higher (24.99 MJ/kg) than in Scenario 1 (23.63 MJ/kg), demonstrating the beneficial effect of spiral pre-treatment on OPC performance.

The product and discard ash for the OPC in Scenario 1 was 18.3 % and 41.9 % respectively. The OPC product yield was therefore 72.9 %. The product and discard ash for the OPC in Scenario 2 was 14.9 % and 32.2 % respectively. The OPC product yield was therefore 72.4 %. This shows consistency in the performance of the OPC as the upgrade in both scenarios are similar with similar yields.

Evaluating the overall fines circuit yields, Scenario 1 = 2.5 % overall yield to middlings, Scenario 2 = 2.8 % overall yield to middlings/export. The decision will be a function of economic value add, prices and rail constraints. Based on the above data, additional beneficiation using the Gravitas technology is possible for particles coarser than 0.212 mm, which requires effective desliming of circuits to realise this benefit.

5. Conclusions

With this study assessing the ability of the Optima® Classifier to meet RB1 specifications, the direct processing of cyclone underflow (U/F) in the OPC demonstrated an increase in calorific value (CV), particularly in coarser fractions, rising from 21.31 MJ/kg to a peak of 28.99 MJ/kg. However, ultra-fine particles (<0.15 mm) limited the final CV to 23.63 MJ/kg, preventing the product from meeting the RB1 target of 27.00 MJ/kg. Spiral pre-treatment of cyclone U/F slightly improved fine coal rejection, enhancing separation efficiency of the OPC. Despite these improvements, ultra-fines continued to lower the overall product CV to 24.99 MJ/kg, highlighting the challenge of fine particle contamination. A direct comparison of the spiral and OPC performance indicated two key differences in the performance of the units. The first is that the spiral product per size fraction peaked at 24.65 MJ/kg in the -1.5+0.212 mm range. The OPC product on the other hand peaked at 27.24 MJ/kg within the same size range. Further work is required to better understand the flowsheet, and economics of using the OPC as a secondary beneficiation stage as there will be trade-offs and dependence on market conditions.

6. Recommendations

To optimize product quality and maximize revenue, improvements in desliming and screening could be considered. With primary challenge in both scenarios are the impact of fines (-0.15 mm) on calorific value and ash content. Optimizing the desliming process by further refining the cyclone cut size to 0.15 mm and incorporating high-energy wet screening post-OPC could improve fine coal removal, enhancing the overall product grade. Additionally, a two-product strategy could be implemented to better align with market demands. Given that OPC achieved 27.00 MJ/kg in the course fractions, a specialized screening stage after OPC could separate the material into RB1 (coarse fraction, ~27 MJ/kg) for export and RB3 (fines, ~23 MJ/kg) for the domestic market. This would enable the plant to generate higher revenue by increasing premium export product yield while maintaining a secondary stream.

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