

# Fines circuit performance evaluation

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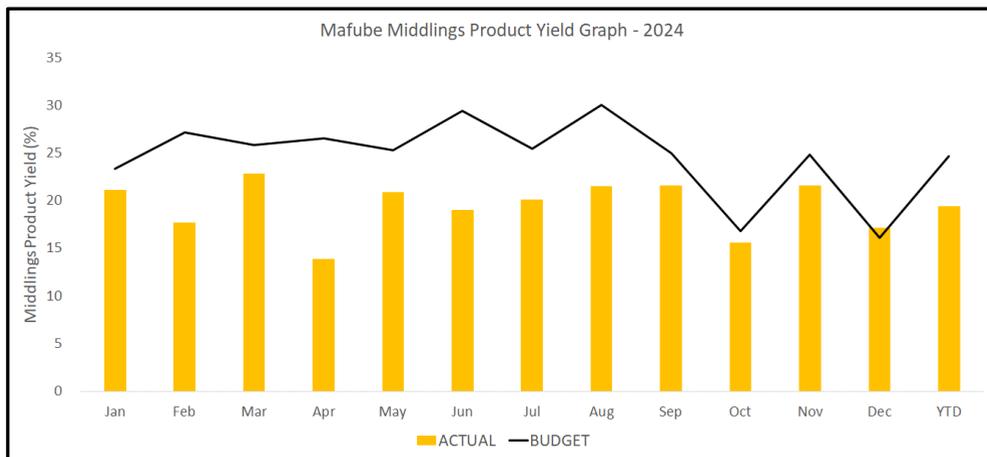
**Abstract.** The Mafube processing plant encountered significant discrepancies between the actual yield of middling product compared to the yield predicted by the geological model. This triggered a review of the performance of the coarse-fines circuit given its significant contribution to the middlings product. This paper presents the results of performance measurements conducted on the coarse-fines circuit performance to understand existing performance and improvements required. The Mafube coarse-fines circuit beneficiates coarse-fines within the particle size range from -0.50mm to 0.150mm and consist of the low-cut density three product (LC3) spirals and the teetered bed separator (TBS). The LC3 spirals operate as the primary beneficiation circuit of the coarse-fines whereas the TBS serves as a secondary upgrade stage, to achieve a target overall coarse-fines calorific value (CV) upgrade of 5 MJ/kg. The LC3 spirals results indicated an efficient performance in the primary beneficiation circuit with a CV upgrade of 3.2 MJ/kg with an ash yield of 51%. The secondary beneficiation stage in TBS indicated a further coarse-fines upgrade CV of 1.55 MJ/kg, thus yielding an overall coarse-fines CV upgrade of 4.82 MJ/kg from the Mafube coarse-fines circuit. Notably, the TBS discard stream showed a CV quality of 21.90 MJ/kg which still meets the Mafube middlings product specifications, thus indicating additional potential to capture the Mafube coarse-fines circuit's discard stream as middlings product. A further feasibility study must be conducted to evaluate the potential gains of capturing the Mafube coarse-fines product for the RB2 export stream and the coarse-fines discard for the RB4 middlings stream.

## 1. Introduction

Mafube Coal (Pty) Ltd. is a 50/50 joint venture between Exxaro and Thungela Resources Limited. Mafube is situated about 30km east of Middleburg in Mpumalanga Province and is located about 20km North of Eskom's Arnot power station.

Mafube is an opencast coal operation which produces seaborne traded RB2 thermal coal and RB4 middlings coal. Mafube has about 1,000 permanent employees and contractors, and its life-of-mine is until 2043.

For the first half of 2024, Mafube encountered significant discrepancies between the actual middlings product yield and the predicted yields. Figure 1 shows a graph of the Mafube actual middlings product yield compared to the budget yield in 2024 and indicates that the actual yield was well below the budget yield until around September 2024.



**Fig. 1.** The Mafube middlings product graph comparing actual against budget yield.

The Geology and Metallurgy teams conducted a joint study to establish the root cause for the discrepancies. The joint study discovered that the geological model inputs for the coarse-fines added back, was based on old data when Mafube was still mining the Springboklagte reserve. This triggered the need to review the performance of the coarse-fines circuit to ensure that the factors used on the geological model reflected the actual performance of the coarse-fines circuit for the Nooitgedacht reserve which Mafube is currently mining.

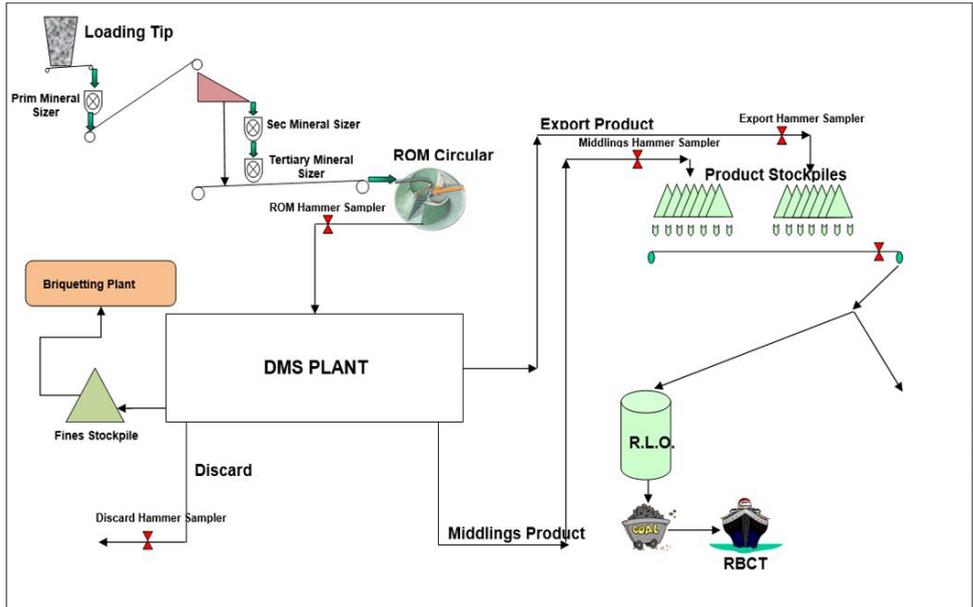
The review of the coarse-fines circuit performance was aimed at establishing the efficiency of the desliming circuit to remove ultrafines material which have poor quality and can negatively impact the performance of the coarse-fines circuit. The review was further aimed at determining the effectiveness of the coarse-fines circuit to beneficiate the coarse-fines to expected levels whereby it can produce both RB2 export and RB4 middlings. Lastly, the review of the coarse-fines circuit performance was also aimed at establishing if the circuit can achieve the industry standard CV upgrade of 5.00 MJ/kg.

## 1.1 Mafube process description

### 1.1.1 Overall process value chain

The reclaimer feeds the surge bin which provides a constant flow of material to the preparation screen which separates the ROM to -50+12mm and - 12mm size range. The -50 +12mm size range is fed to the Course Low Gravity (CLG) Dense Medium (DM) cyclone. The -12mm size range is screened at the desliming screen where the (-12+0.63mm fraction) is fed to the Small Low Gravity Dense Medium (SLG) cyclone. The product of both CLG and SLG cyclones is dewatered by the centrifuges and conveyed to the export stockpile (RB2).

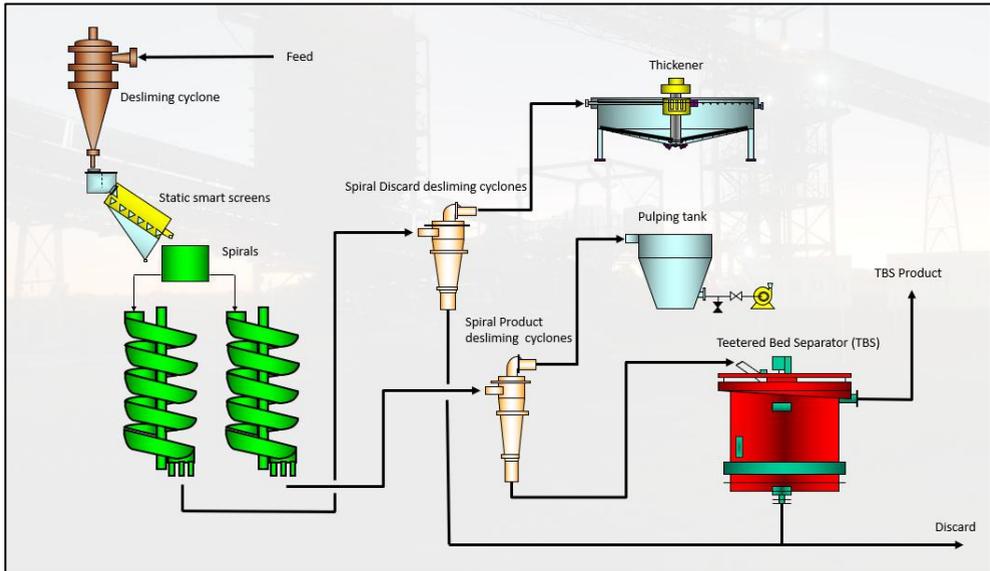
The underflows of the CLG and SLG DM cyclones are mixed with medium and fed to the High Gravity Cyclone (HG). The product of HG cyclones is dewatered by the centrifuges and conveyed to the middlings stockpile. The underflow of the High Gravity cyclone is dewatered and conveyed to the discard dump



**Fig 2.** Overall Mafube process value chain

### 1.1.2 Fines circuit

The undersize of the desliming screen (-0.63mm) is fed to the desliming cyclone. The desliming cyclone underflow proceeds to the spirals where the spiral product is fed to the TBS for upgrading. The desliming cyclone overflow feeds the thickener. The thickener tailings are pumped to the Filter Press Plant. Refer to figure 3 below.



**Fig. 3.** Fines circuit

## 1.2 Mafube products

Mafube primary circuit produces seaborne traded RB2 thermal coal with a minimum CV of 26.50 MJ/kg at a minimum net calorific value of 5,800 kcal/kg. The secondary Mafube product is the RB4 middlings with a minimum CV target of 20.80 MJ/kg and net calorific value of 4,600 kcal/kg. Most of the middlings product is sold locally as power station coal.

## 2. Literature review

### 2.1 Spirals

Spirals were introduced in South Africa in the early to mid-1980s and quickly became an effective and cost-efficient method for recovering fines (Holland-Batt, 1995). It is evident that fine coal in the size range 0.5 to 0.15 mm could be beneficiated using the spirals. The solids percentage of the feed to the spirals should be 35% to accommodate some hindered separation but at the same time provide sufficient water to move the particles down the spirals. They further stipulated that it is difficult to feed 16 starts with the same quantity of material and the beaching of solids on the walls of the spirals.

The fines circuit at Mafube is supplied with de-slimming screen underflow, typically at -0.63 mm, with a P80 of 0.5 mm. This feed then moves to the spirals, which serve as the primary separation stage in the circuit. Meanwhile, the overflow from the de-slimming cyclone is directed to the thickener, and the thickener underflow is pumped to the filter press plant.

### 2.2 TBS

Hindered Bed Separators are gaining widespread acceptance as fine coal beneficiation devices across the globe. They are primarily being used to replace or complement spiral plant installations. The industry increasingly recognizes hindered bed separators as an effective

tool for processing fine material (-2 mm, +150 μm), especially in the coal sector (Galvin et al., 1999)

It has been found that by varying the flow of fluidisation water the unit can separate either on size or density based on a phenomenon known as bed inversion. With low fluidisation water flowrates, the more the dense particles remain closer to the bottom of the unit whereas the less dense particles percolate through the bed and are carried over the top of the unit (Galvin et al., 1999).

On the TBS the slurry feed enters the unit tangentially via the feed well, then a fluidized or a teetered bed is built against a TBS fluidized water supply. A steady state will then be achieved where the particles of the feed, which are lighter will have a hindered settling velocity which is less than the average TBS fluidizing water velocity. These light particles will tend to float on top of the teetered bed and hence will report to the overflow stream. Particles with higher density than the teetered bed will have a hindered settling velocity greater than average TBS fluidizing water velocity, these particles will then report to the spigot valves at the bottom of the TBS machine (Drummond, Nicol, & Swanson, 2002).

Drummond et al. (2002) further stated that for the TBS unit to operate effectively, the average relative density of the bed must be kept constant. This is achieved by employing capacitance type differential pressure cell, which measures the effective density of the teetered suspension. The effective density is compared to the operating setpoint, and the spigot valve is actuated to discharge excessive bed solids if the effective density is too high. The ratio of the coarse to the fine size fraction should be 5-6:1.0. Maintaining the size to be treated within this range will minimize coarse coal losses to TBS discard and entrainment of high ash fines in the TBS product.

### 2.3 Use of TBS for spiral product upgrade

TBS can be used as a single-stage or two-stage process to separate raw coal. Additionally, it may serve as a spiral product upgrade, as is the case at the Mafube plant. Before being fed into the TBS machine, the spiral product stream must be dewatered and deslimed to remove any ultrafines. Refer to figure 4.

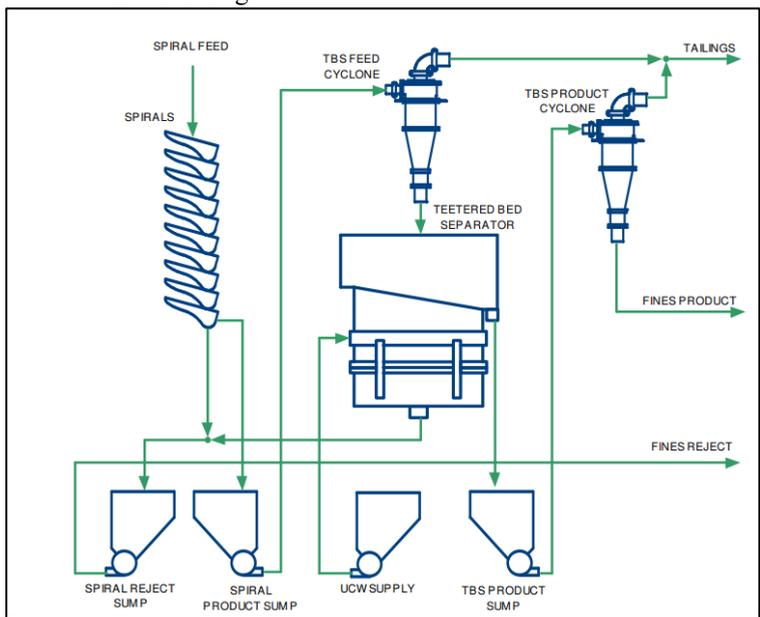


Fig. 4. TBS is used as a spiral product upgrade (Drummond et al., 2002)

### 3. Methodology

A sampling campaign was conducted on the fines circuit, with all samples collected in accordance with ISO standards. All the samples were analysed by an accredited external laboratory.

#### 3.1 Spiral circuit

The spiral feed samples were collected sampled and analysed for Particles size distribution. The particle size distribution was also subjected to fraction CV and ash analysis to understand the behaviour of finer particles. The ultrafines tend to report to the product stream in spirals, TBS units and in dense-medium cyclones. The quality of this fraction tends to be very poor, thus degrading the product. Desliming of the product is important to improve the quality of the product and to reduce the moisture content of the product (de Korte, 2008)

Spirals feed, product and discard samples were collected. The spirals feed sample was first analysed for particle size distribution to establish the amount of ultrafines in feed. Thereafter, all the samples for spirals feed, product, and discard were analysed for ash and CV to determine the spiral circuit's upgrade capabilities and yield. It is important to note that these samples were taken while the splitters or cutters were on position number 2. Figure 5 below indicates the spiral cutter position when the samples were collected.



Fig. 5. The LC3 spiral cutter position when the samples were collected.

#### 3.2 TBS Circuit

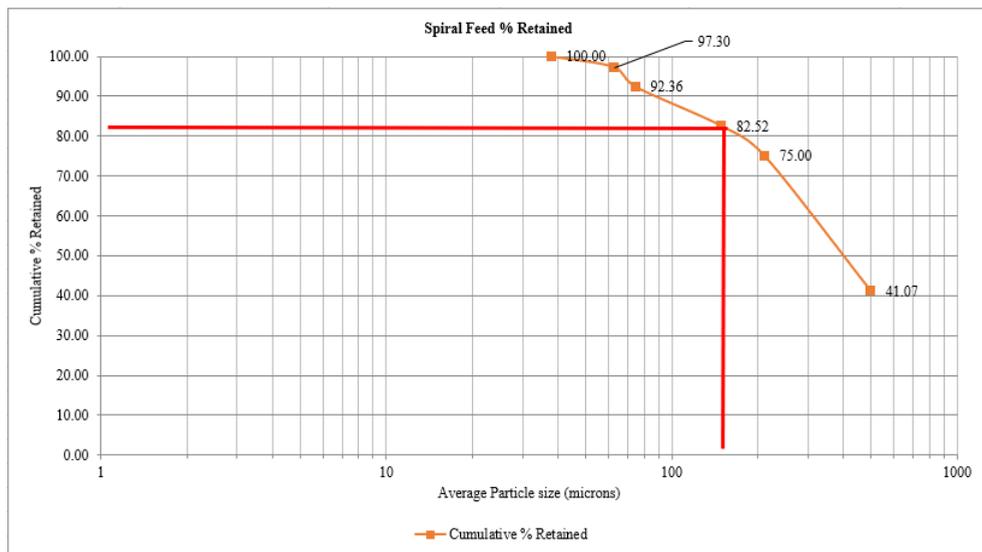
TBS feed, product and discard samples were collected and analyzed for ash and calorific value CV to determine TBS circuit's upgrade capabilities and yield. The TBS samples were taken at various feed densities and flowrates.

### 4. Results and discussion

## 4.1 Spirals

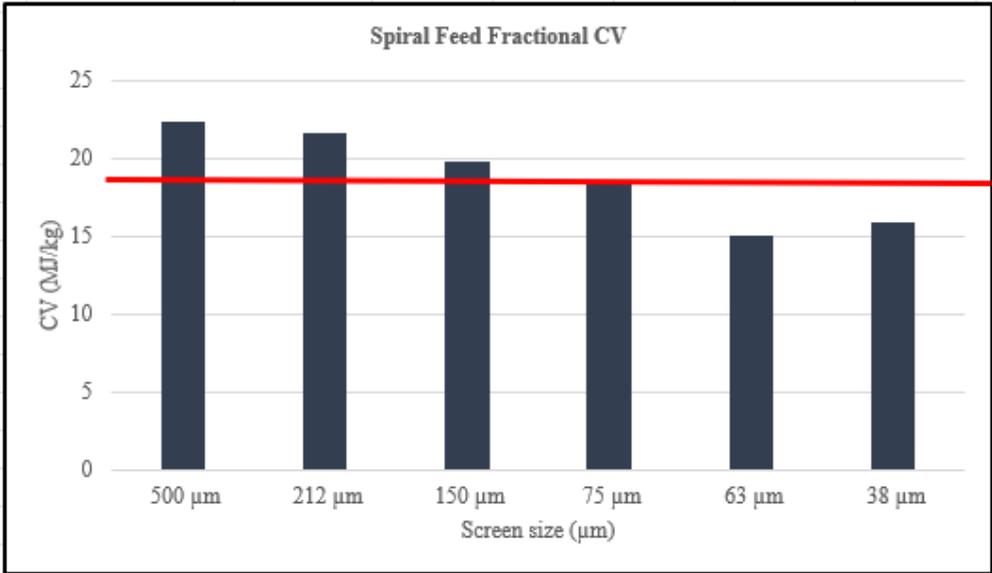
### 4.1.1 Spirals feed results

The graph in Figure 6 below shows the particle size distribution results of the spiral feed. It clearly indicates that 82.52% of the material above 150 microns reports to the spirals. This suggests that 17.5% of ultrafines are being processed through the spirals, which may impact the quality of the spiral feed.



**Fig. 6.** Spiral feed PSD analysis.

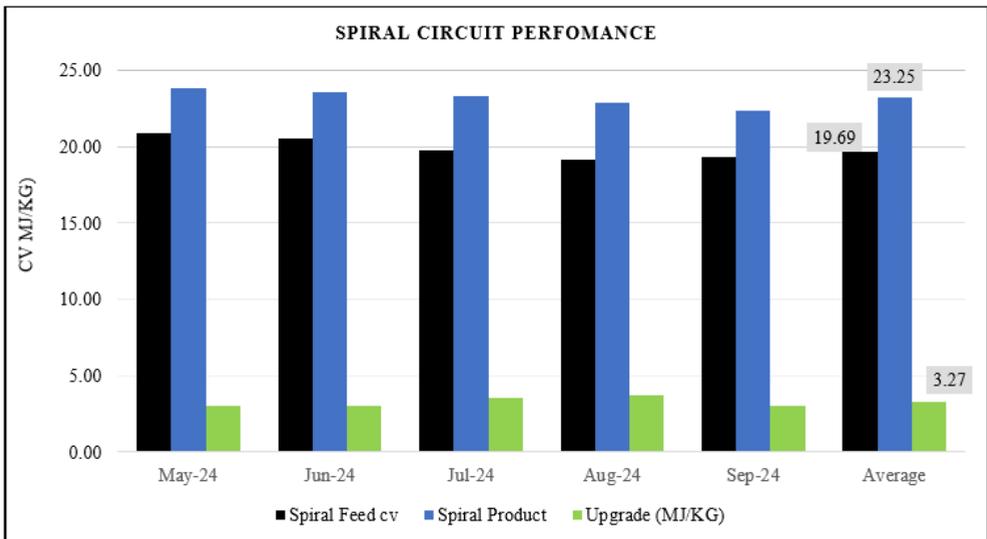
Figure 7 below shows the particle size distribution results of the spiral feed. The data clearly indicates that particles larger than 150 microns have a higher CV, exceeding 20 MJ/kg, and this is considered good quality for the Mafube middlings product. However, it also shows that as the particle size decreases, the CV drops to levels below the middlings product target specifications. These lower CV quality particles can negatively impact the overall performance of the spirals circuit if not properly managed.



**Fig. 7.** Spiral feed fractional analysis

#### 4.1.2 Overall spirals results

The spirals performance results are shown in Figure 8 below. The data reveals that on average, the spirals feed CV was 19.69 MJ/kg and was upgraded to a CV of 23.25 MJ/kg, thus representing an overall average CV upgrade of 3.27 MJ/kg.



**Fig. 8.** Spiral circuit results

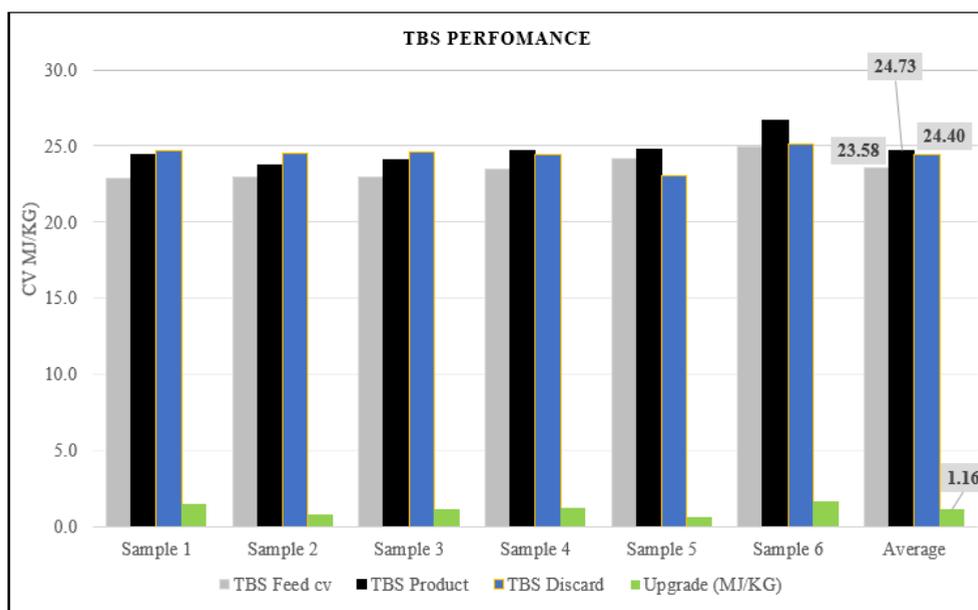
The overall CV upgrade on the Mafube spirals circuit indicates a well-functioning circuit relative to the quality of feed received and shows that the spirals circuit performance is on average able to upgrade its feed to a quality above the Mafube middlings product target specifications.

## 4.2 TBS

### 4.2.1 Initial TBS results

The TBS performance results shown in Figure 9 below represent the first test where the TBS was operating within a specific range of 1.15 to 1.25 SG. The fluidizing water flow rate was maintained at 200 m<sup>3</sup>/hr.

The results indicate poor separation in the TBS, with the average feed CV of 23.58 MJ/kg, being upgraded to 24.73 MJ/kg. This poor separation can be attributed to the low density of the TBS bed. According to Galvin et al. (1999), optimal separation in a TBS occurs in a suspension whereby the operating density is as close as possible to that of the lower ash coal particles.



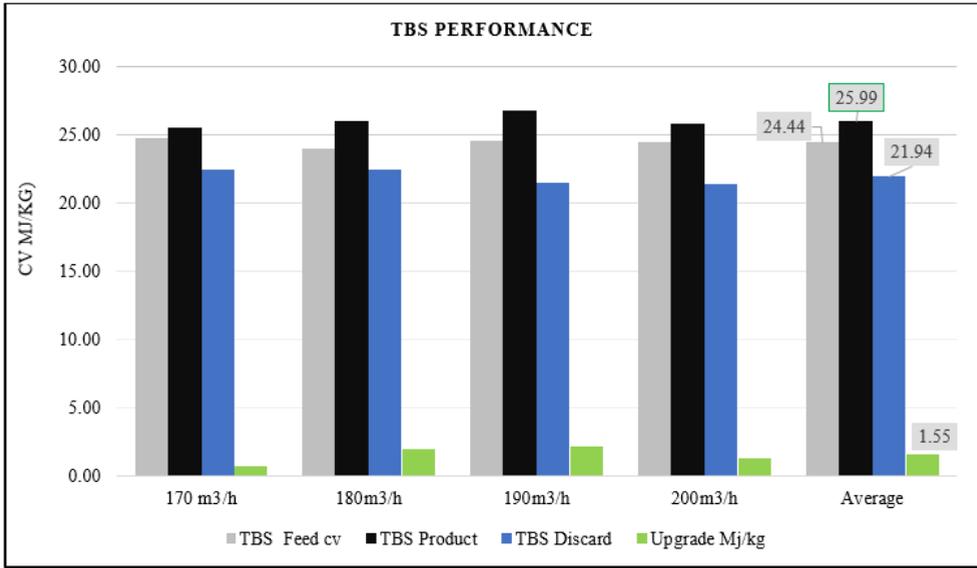
**Fig. 9.** TBS results at 1.15 to 1.25 SG

The lower-than-expected overall TBS CV upgrade, necessitated for circuit to be operated at high density and various flowrates to establish the optimum operating conditions that would yield the optimum TBS circuit performance.

### 4.2.2 TBS results at various flowrate settings

During the second phase of testing, the feed conditions of the TBS were adjusted. The TBS bed density was increased to 1.32 SG, and samples were taken at varying fluidizing water flowrates.

The results shown in Figure 10 below indicate improved performance, with an average CV upgrade of 1.55 MJ/kg.



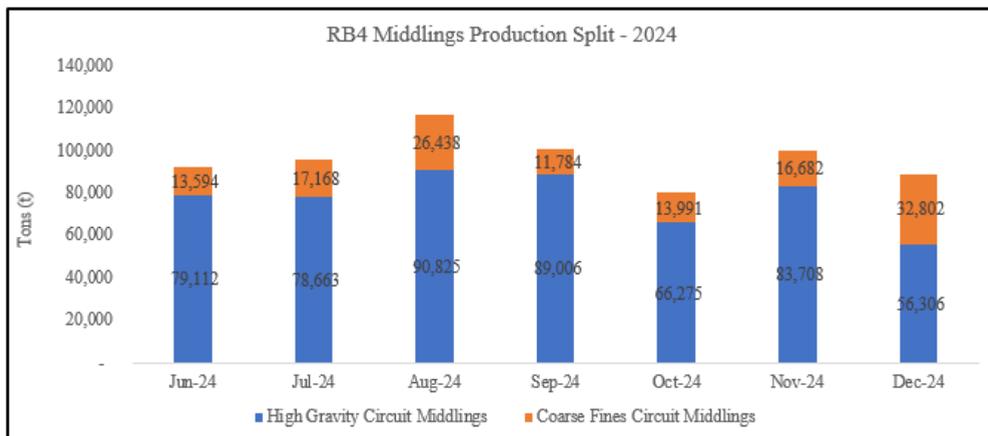
**Fig. 10.** The TBS results for the bed density settings of 1.32 SG at various water flowrates.

The results of the second phase of testing further indicate that the TBS settings of 1.32 SG and fluidizing water flowrate of 190m<sup>3</sup>/h achieved optimum TBS performance with an average CV upgrade of 1.55 MJ/kg This indicates that the coal particles on the Mafube TBS are well fluidized for optimum separation at a flowrate of 190m<sup>3</sup>/h and a high bed density of 1.32 SG.

### 4.3 Overall coarse-fines circuit performance

Figure 8 shows that the spirals circuit achieved an average CV upgrade of 3.27 MJ/kg from an average feed CV of 19.69 MJ/kg. The TBS circuit was able to achieve an average CV upgrade of 1.55 MJ/kg when operated at its optimum settings of 1.32 SG and flowrate of 190m<sup>3</sup>/h. This indicates an overall average coarse-fines circuit CV upgrade of 4.82 MJ/kg on the coarse-fines fed to the coarse-fines circuit for beneficiation. The targeted overall CV upgrade of the coarse-fines was 5.00 MJ/kg to enable for these fines to interchangeably be added to either the RB2 export or RB4 middlings stream depending on the quality of the feed material. Achieving an overall CV upgrade of 4.82 MJ/kg, indicates that the coarse-fines circuit is performing within the target beneficiation levels and enables Mafube to be flexible in either sending the coarse-fines circuit product to either middlings or export product stream.

Following the optimization of the coarse-fines circuit, Mafube took a decision in June 2024 to add all the coarse-fines circuit product onto the middlings product stream and a scale was installed coarse-fines product conveyor to quantify the impact of the upgraded coarse-fines product on the overall middlings yield. Figure 11 below shows the Mafube middlings product split between the middlings product from the secondary beneficiation circuit (high gravity circuit) and the coarse-fines circuit.



**Fig. 11.** The Mafube middlings product split following the coarse-fines circuit upgrade.

The results from Figure 11 indicates that the coarse-fines circuit product is on average 20% of the total Mafube middlings product. This is a significant figure and the results from Figure 1 shows that upgrade of the coarse-fines circuit and the use of the correct factors on the geological model as per the actual performance of the coarse-fines circuit, helped reduce the variance between the actual and budget middlings yield. It is for this reason that the coarse-fines circuit’s product continues to be added onto the middlings product stream to help improve middlings qualities and yield. However, the overall CV upgrade on the coarse-fines circuit of 4.82 MJ/kg indicates that Mafube should consider being flexible to either be able to add the fines to the RB2 export or RB4 middlings product stream depending on the quality of the feed to the coarse-fines circuit.

## 5. Conclusion

The spirals circuit results showed strong performance, with an average CV upgrade of 3.27 MJ/kg. This positive outcome can be attributed to the effective operation of the desliming circuit to remove the ultrafines material which tends to have poor CV quality and can negatively impact the spirals performance. The particles size distribution of the spirals feed samples indicated fewer ultrafines reporting to the spiral circuit, thus limiting the presence of poor-quality material which might have otherwise negatively impacted the spirals performance.

The TBS circuit achieved an average CV upgrade of 1.55 MJ/kg and its optimum operating conditions we established to be at a bed density of 1.32 SG and fluidizing water flowrate of 190m<sup>3</sup>/h. The TBS circuit performance improved when the operating density was increased to 1.32 SG and the improved performance further supported by Galvin et al. (1999a), who stated that optimal TBS separation occurs in a suspension with a relatively high density which is as close as possible to that of the lower-ash coal particles. The combined average overall coarse-fines circuit CV upgrade achieved by the spirals circuit and the TBS circuit was found to be 4.82 MJ/kg.

The coarse-fines circuit overall CV upgrade of 4.82 MJ/kg indicates that the circuit is operating at the expected levels of beneficiation and that it can be able to beneficiate fines to the RB2 export product specification when the plant receives good quality run-of-mine coal. The performance of the coarse-fines circuit further shows that Mafube can be flexible in managing the coarse-fines circuit product by deciding whether to add the fines to either the RB2 export or RB4 middlings stream, while ensuring that there is no fines lost to the discard stream.

## 6. Recommendations

The overall performance of the coarse-fines circuit indicate that the circuit is operating at the expected beneficiation levels and the destination of the coarse-fines product to either the RB2 export or RB4 middlings stream, depends on the quality of the feed material. It recommended that Mafube employees a flexibility strategy to be able to divert the coarse-fines product to either RB2 export or RB4 middlings stream based on the quality of the feed material. The TBS results on figure 10, indicate that when it operates optimally and the circuit feed qualities are good, the TBS discard quality is of RB4 middlings product specification, and therefore there exist an opportunity for Mafube to further capture the TBS discard onto the RB4 middlings stream when the TBS product is being sent to the RB2 export stream.

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