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Separation efficiency of XRT sensor sorting technology on coarse particle size fractions in coal processing

Shannon McEwan[1,*], and *Dion* Lusinga[1]

[1]IMS Engineering (Pty) Ltd, 10 Derrick Road, Spartan, Kempton Park, Gauteng, South Africa

Abstract. The application of X-ray transmission (XRT) sensor sorting technology in coal processing has gained significant attention due to its potential to enhance separation efficiency, reduce operational expenditure, and improve overall plant performance through an entirely dry process. This paper presents an in-depth analysis of the separation efficiency of an XRT sensor sorter applied to coarse particle size fractions in coal. Focusing on particle sizes greater than 20mm, the study evaluates key performance indicators such as yield, ash and sulphur reduction, increase in calorific value as well as a theoretical comparison to gravity separation. Data from testing coal on a commercial scale sorting plant and laboratory results are utilized to demonstrate the impact of various operational settings on the separation efficiency across coal run-of-mine samples sourced from a variety of mines across South Africa. The findings reveal that XRT technology offers distinct advantages in precision separation by distinguishing between coal and waste material with repeatability and reproducibility, making it an effective solution for coarse fraction sorting at a high throughput through a modular parallel installation. The paper will also discuss site related insights related to material handling and particle surface moisture and suggest optimization strategies to enhance the performance of XRT sensor sorters in industrial applications. The insights gained could support further innovation in sustainable coal processing practices.

1 Introduction

Traditionally, coal beneficiation has widely been achieved through technologies that utilise density differentials between coal and impurities as a means of separation, such as Dense Medium Separation (DMS) and jigging for coarse fractions, and spirals for finer fractions. In recent years, alternative technologies that are based on dry separation such as sensor sorters and dry jigs have been explored in the coal industry, however, these technologies have not yet found widespread applications globally. In this paper the application of sensor sorting on coals is presented with a view of adding more insight to the application of alternative technologies in coal production.

2 Separation efficiency

Coal process separation efficiency is typically defined using the EP (Ecart Probable), which ranges from 0 to 1. A low EP value signifies that the separation is efficient, and an EP of 0 means that the separation is ideal. It is reported that the EP of dense medium processes can be as low as 0.02 and that of dry processes like sensor sorters between 0.20 and 0.30 [1]. Another common metric used for measuring plant efficiency is organic efficiency, defined as the actual product yield divided by the maximum product theoretical yield attainable, for a specific ash value. The theoretical yield can be determined by reconstituting the product and discard fractions generated in a washability analysis at different densities. A more detailed discussion on plant efficiency is presented in reference [2].

This paper presents an in-depth study of the separation efficiency of an XRT sensor sorter applied to coarse particle size fractions in coal. It is envisaged that this study will add to the limited body of knowledge currently in the public domain concerning dry coal sorting.

A key highlight of this paper is that while it is possible to attain a high separation efficiency, as defined by a low EP value, using a dense medium process which separates by specific gravity, the maximum commercial benefit from a coal resource, in terms of yield (and operating cost, which is not discussed in the paper), may be realised if an innovative approach to separation is taken using XRT dry sorting technology.

3 Sensor sorters and their working principles

Sensor sorters have been used widely in the diamond industry for decades in the application of final diamond recovery; however, it is in the last 10 to 15 years where sensor sorters have gained adoption across a wider range of commodities such as copper, gold, tungsten, coal, industrial minerals, lead and zinc.

The working principle of sensor sorters is that they exploit differences in the physical and chemical properties of mineral ores to separate valuable minerals from waste. Material presented to the sorter is separated using differences detected using various sensors such as X-ray Transmission (XRT), Infra-red (IR), Colour, Induction, X-ray Fluorescence (XRF), Laser and X-ray luminescence (XRL).

Material is conveyed in a mono layer in the sorter and passes through a single or multi-sensor system that is used to analyse differences between the various constituents of the ore, and thereafter, a signal is sent to an ejection system to eject waste particles, typically an electro-pneumatic valve bank. The sorter may also be programmed to eject product particles and retain waste particles. The ejected and retained fractions from the sorter are discharged into two separate chutes and onto two separate conveyor belts, for stockpiling or for further processing downstream.

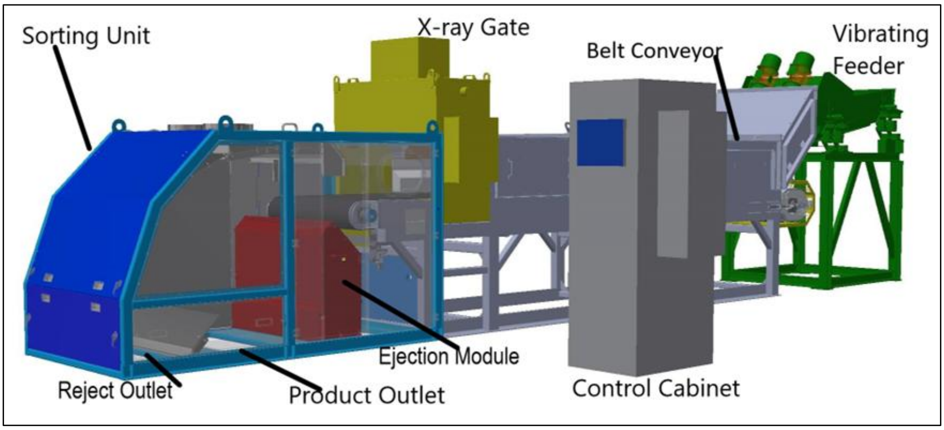


Fig. 1. XRT Sorter schematic

4 Configuration of a sensor sorter and general testing methodology

There are various ways in which a sensor sorter can be configured to sort material on a site; however, the basic method typically entails pre-selecting waste and product particles from the deposit to be treated and scanning the particles in the sorter. The raw images of the scans are then processed through the manufacturer's exclusive sorting program, and ultimately the sorter is programmed to make a distinction between product and waste based on the pre-classified particles. When Run-of-Mine ore or tailings are fed into the sorter, the system analyses every particle individually and then classifies each particle as either waste or product.

The scanning procedure used for the sorting tests is illustrated in Fig. 2, below.

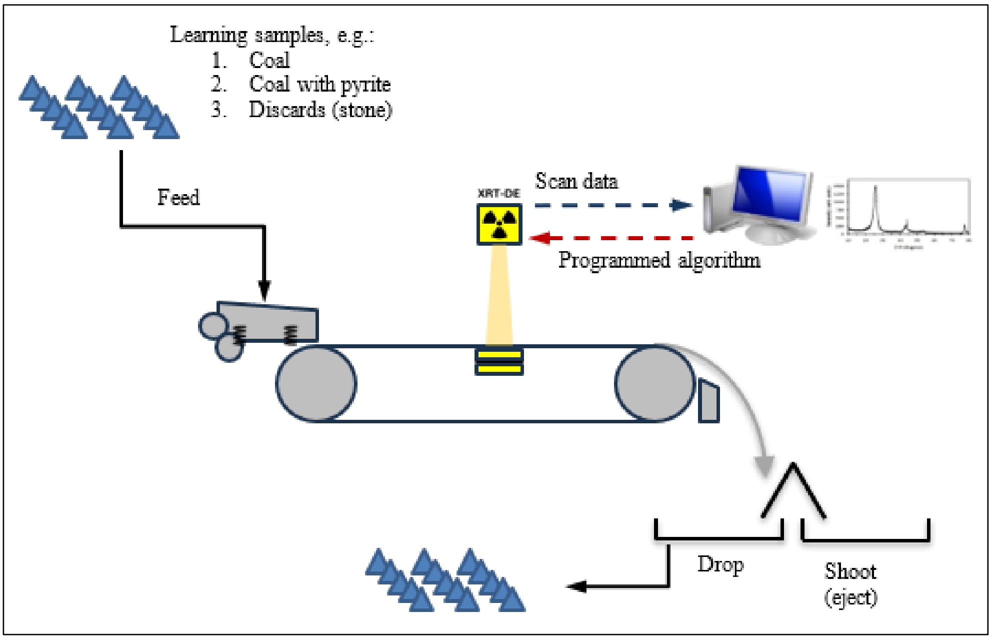


Fig. 2. Schematic diagram illustrating how the material is processed, that has been pre-classified by a geologist

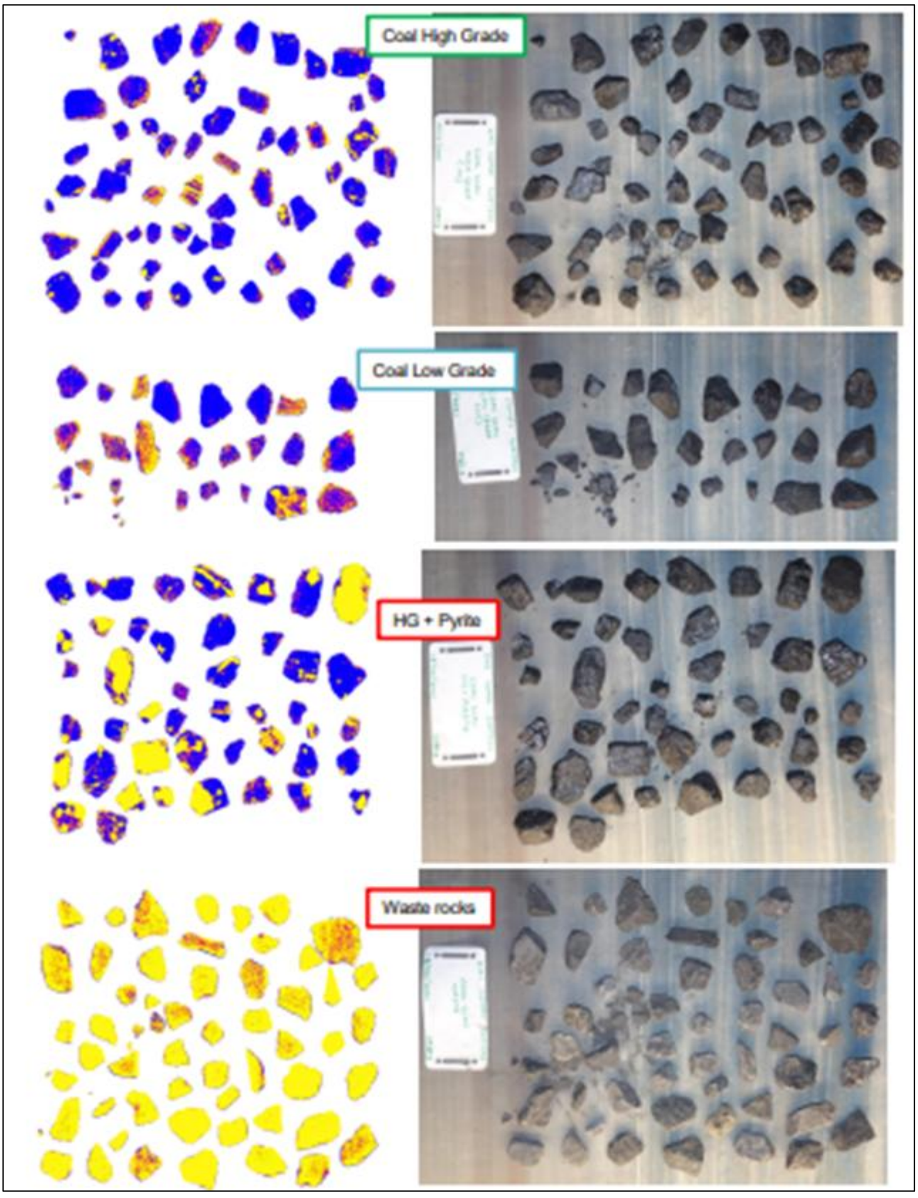


Fig. 3. Processed images of thermal coal sample: High grade, low grade, high grade with pyrite, and waste rocks

Once the sorter has been programmed, some scoping tests are done, typically designed in such a way in which a grade-recovery curve can be created. This involves testing the ore using different settings and assaying the sorted waste and product from each setting. Simple examples of grade-recovery curves derived from the scoping tests are shown for coal processing.

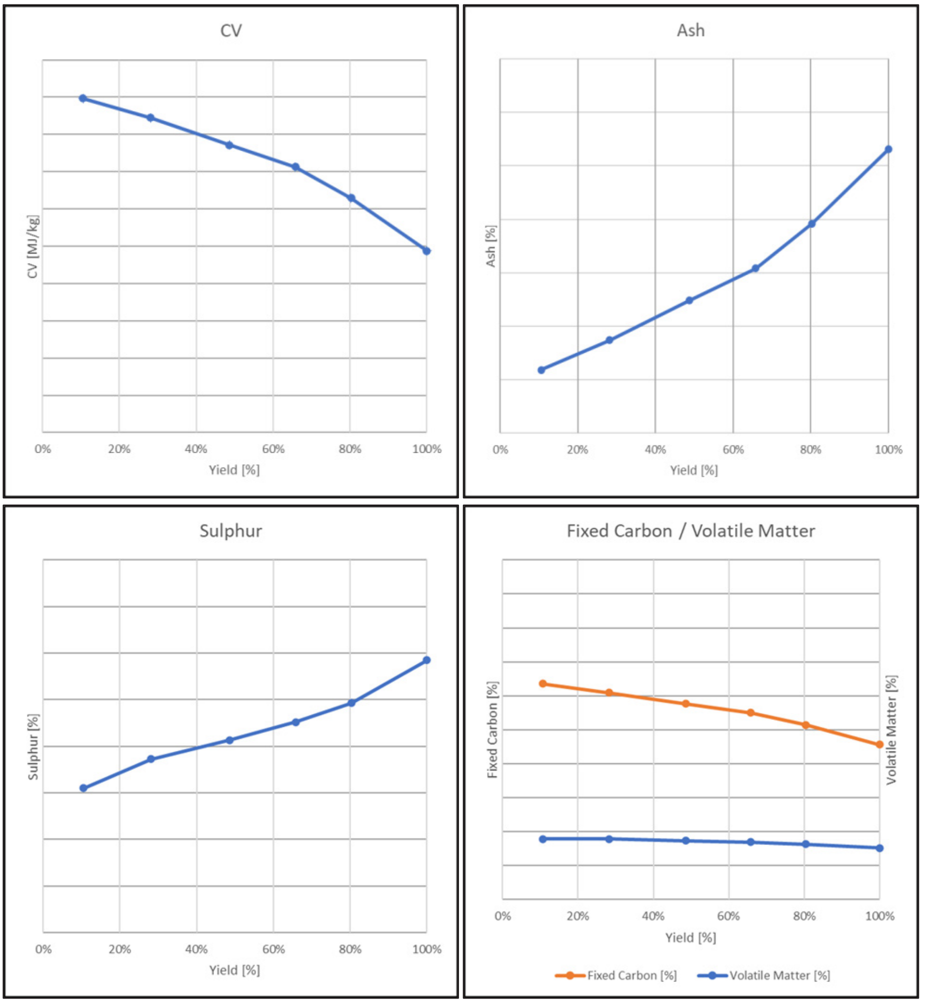


Fig. 4. An example set of scoping test grade-recovery curves for coal

Once the grade recovery curves are established then a sorter setting is selected to generate a yield that is closest to the required % ash and/or any other coal quality metrics that the client requires and a first bulk test run is completed. A bulk test is run at the target setting and the proximate analysis, CV, and % sulphur results compared to the theoretical grade recovery data.

If required, the sorter setting can be adjusted and the bulk test rerun. This would be an optimisation step.

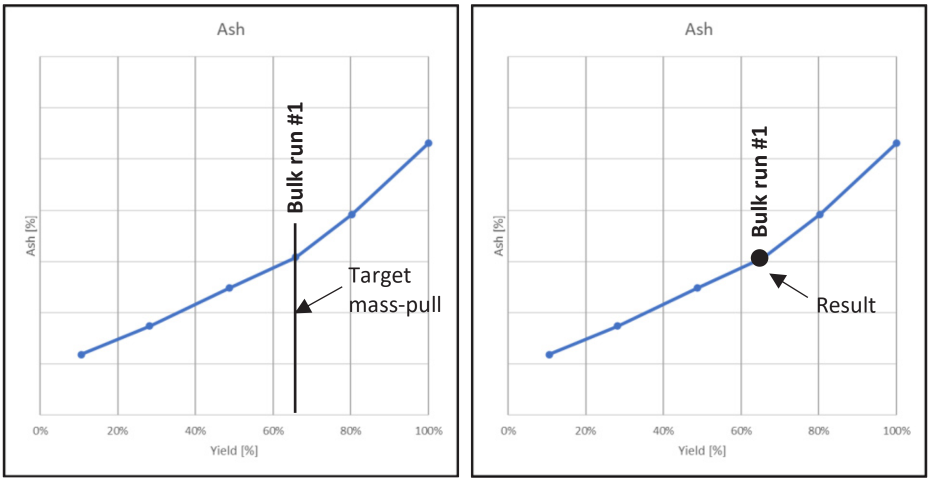


Fig. 5. Example of bulk run #1 target selection (left) and result (right)

Once the sorter settings are established for the initial bulk run, then two additional bulk runs are completed at the same target, or targets slightly offset from the initial target setting.

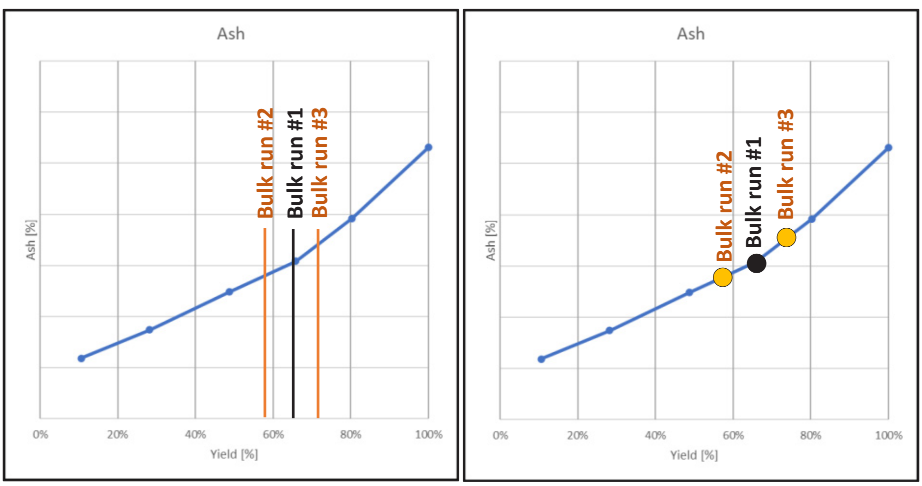


Fig. 6. Example of bulk run #2 and #3 target selection (left) and result (right)

For these two bulk test runs, full washability analyses are done and the proximate analysis, CV, and % sulphur results compared to the theoretical grade recovery data. The separation efficiencies are determined, i.e., EP and Organic Efficiency values, for the sorter separation.

5 Case study background and results

In the present study, a sample from Mine A was tested in a commercial scale XRT sensor sorter at IMS Engineering. The particle size tested in the sensor sorter was -55mm +20mm, whilst the –20mm fraction was tested in a wet jig. The testing protocol described in the preceding section was used for the sorting tests. Fig. 7 shows the relationship between ash and yield of the feed in a washability test performed by an independent laboratory, and the performance of the sorter when the material was tested using various settings. The mine's ash target as defined in their contract with an electricity power supplier is (≤26.2%) and it is represented by the horizontal line in the graph.

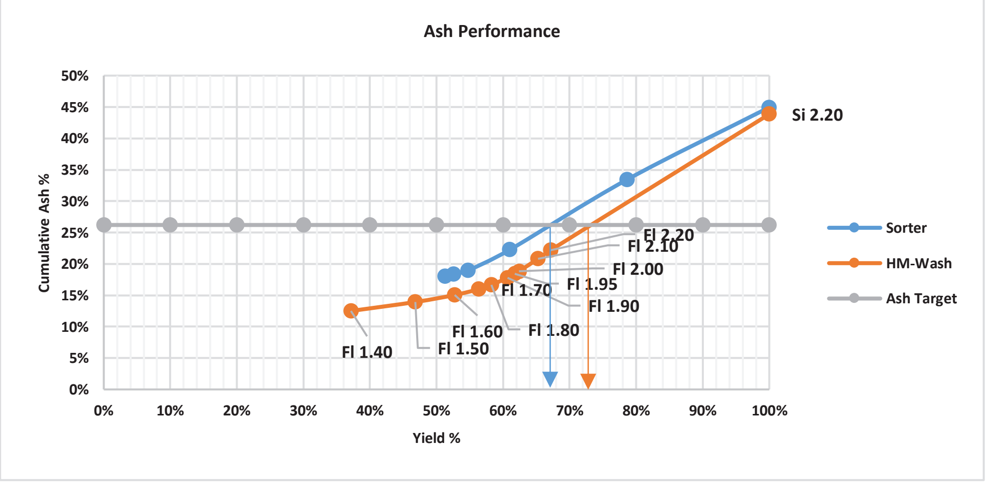


Fig. 7 Ash performance of laboratory washability and sorting performance

Fig. 7 shows that with the required ash content, a sensor sorter would generate a yield of 67.0% and an ideal separation by density would generate a yield of 72.8%.

Fig. 8 shows a similar relationship for a laboratory washability and a sensor sorter on sulphur on the same feed shown in Fig. 7. The mine's contractual sulphur target (≤0.96%) is represented by the horizontal line in the graph.

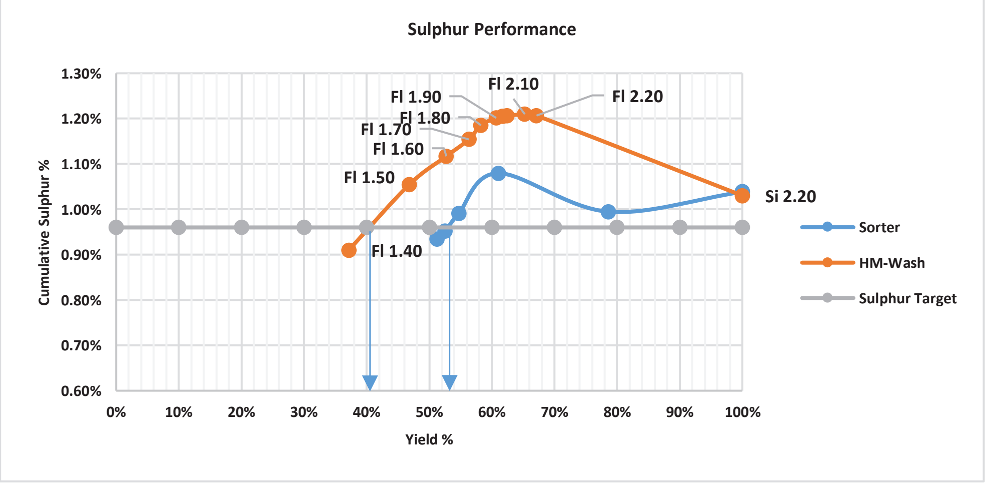


Fig. 8 Sulphur performance of laboratory washability and sorting performance

Fig. 8 shows that with the required sulphur content; a sensor sorter would generate a yield of 53.0% and an ideal separation by density would generate a yield of 40.5%.

5.1 Sulphur limitations on yield

Based on the findings from Fig. 7 and Fig. 8, the yield limiting factor is the sulphur content. In other words, when considering ash alone, yields of between 67.0% and 72.8% can be achieved within ash targets, however when considering sulphur, yields of between 53.0% and 40.5% can be achieved, with a sensor sorter and an ideal heavy media separator, respectively. In this instance, the sensor sorter achieves a higher yield by 13.5% (+30.9% relative), due to the ability of the sensor sorter to target pyritic sulphur directly, based on the associated Fe content and not the relative density.

5.2 Bulk Tests

The feed required product specifications, ideal heavy media and sorter performances are shown in **Table 1**. In addition, results of three bulk tests performed on the sorter to verify the outcomes of the scoping tests are shown.

Table 1. Mine A feed, required product specifications, feed washability, and sorting results

	Ash (%)	Sulphur (%)	CV (kJ/kg)	Yield (%)
Feed (typical)	43.9	1.03	17.06	100.0
Required product (contractual limits)	26.2	0.96	22.30	45.0 (from plant data)
Feed sink/float product†	12.5	0.96	26.88	40.5 (from washability)
Initial sorter product (scoping)	18.5	0.96	25.50	53.1
Bulk test 1 (setting a)				
Feed	45.7	0.99	15.38	100.0
Sorter product	20.2	0.84	24.44	53.7
Bulk test 2 (setting a)				
Feed	44.1	1.05	15.72	100.0
Sorter product	21.9	0.81	23.96	57.1
Bulk test 3 (setting b)				
Feed	42.8	1.10	16.65	100.0
Sorter product	15.8	0.82	25.51	58.0

Bulk Test 1 and 2 were performed using the same settings (sensitivity) on the sorter and in Bulk Test 3 the settings or sensitivity was reduced to increase the yield, by accepting atomically denser material into the floats fraction without breaching the sulphur limit, as was required by the client's contract specification. Since the sulphur content of the product was still below 0.96%. i.e. in the range of 0.81% and 0.84%, further testing can be done to increase the yield beyond the 53.7% and 58.0% range. On a sorter, this can be done electronically by increasing the set point (sensitivity) that allows coal with more atomically dense inclusions

† Sink/float may be used interchangeably with washability and heavy medium process. The product specifications defined as "sink/float product" refer to the floats' quality when the sulphur content is 0.96% (maximum allowed)

into the product. However, the contractual product specifications as detailed in **Table 1** must not be breached.

5.3 Separation efficiency

Based on the heavy medium analysis of the feed, an ideal density-based separation would generate a yield of 40.5% (see **Table 1**). This is based on the constraint imposed on the yield by sulphur (0.96% limit). The sensor sorter however, generated a yield of up to 58.0% before the sulphur limit was reached. At a yield of 58.0% the sulphur content was 0.82%, and the yield can be increased until a sulphur content of 0.96% is reached.

Table 2. Traditional efficiency parameters applied to sensor sorter

	Bulk Test 2	**Bulk Test 3**
Feed Ash (%)	44.10	42.80
Product Ash (%)	21.90	15.80
Sulphur (%)	0.81	0.82
Yield (%)	57.10	58.00
D50	1.90	1.71
D25	2.10	1.95
D75	1.62	1.50
EP	0.24	0.23
Organic Efficiency (%)	0.86	0.91
Sinks in Floats (%)	4.53	3.35
Floats in Sinks (%)	8.76	5.28

Based on an assessment of the sorter using traditional efficiency parameters, in the current tests, EPs of between 0.23 and 0.24 were obtained, which are higher than those that would be obtained from a dense medium separator, which are typically in the range of ±0.05. The lower the EP value the better the separation efficiency. However, as noted before, the product yield of the sorter is higher than that of an ideal density separator.

The organic efficiency of the sorter, as defined traditionally, ranged between 86.5% and 90.8%, whereas organic efficiencies in the range of 92.9% to 99.8% have been reported for dense medium separators [1, 2].

The misplacement of sinks in floats ranged between 3.35% and 4.53% and the misplacement of floats in sinks ranged between 5.28% and 8.76%, creating a total misplacement of between 8.63% and 13.29% depending on the sorter settings.

5.4 Case study summary

The present study showed that the EPs attained during the test work ranged from 0.23 and 0.24, which are higher than the EPs from typical dense medium separators i.e. ±0.05. However, the yield produced by the sensor sorter was considerably higher at 58% compared to 40.5% for an ideal separator as obtained from a laboratory washability analysis. The higher yield obtained by the sorter was driven by its ability to separate sulphur more effectively than the dense medium separator (represented in this study by a washability of the feed). Based on this, it can be concluded that alternative technologies must be evaluated holistically for business sense as opposed to only technical excellence.

It is also prudent to mention that the operating costs of a dense medium separating plant can be 100% to 200% more than those of an equivalent sorting plant and the capital cost of the same dense medium plant can be up to 75% more expensive than the equivalent sorting plant. The sorting plant would be coupled with a wet or dry jig which will treat the finer fraction that bypasses the sensor sorter.

5.5 Ongoing and future studies

The present study presented a case in which the requirement to desulphurise coal, resulted in a situation in which a sensor sorter produced a higher product yield than a dense medium process (as shown by washabilities and actual plant data in Fig. 7 and **Table 1**). Had sulphur not been a limiting factor or process driver, the washability results showed that a yield of 72.8% would have been attained in a perfect dense medium separator, compared to a 67.0% yield from the sensor sorter, which is a 5.8% difference in yield at the contractual ash limit. In such a case, the relative capital and operating costs of the various technologies become critical to sound business decision making.

Unlike jigs and dense medium separators, XRT sensor sorters do not separate material based on the specific gravity, but on the atomic density of individual particles. Therefore, IMS is giving consideration to the development of appropriate efficiency measurement metrics for sorting in coal and is continuing with:

1. Additional tests on the coal presented in the case study, as well as extending the scope to two more coal sources
2. Case study optimising on EP and not on any client specific requirement as reflected in the current case study
3. Case study investigating the correlation of EP and/or organic efficiency to specific coal product ash and sulphur requirements
4. Other efficiency metrics for sensor sorters

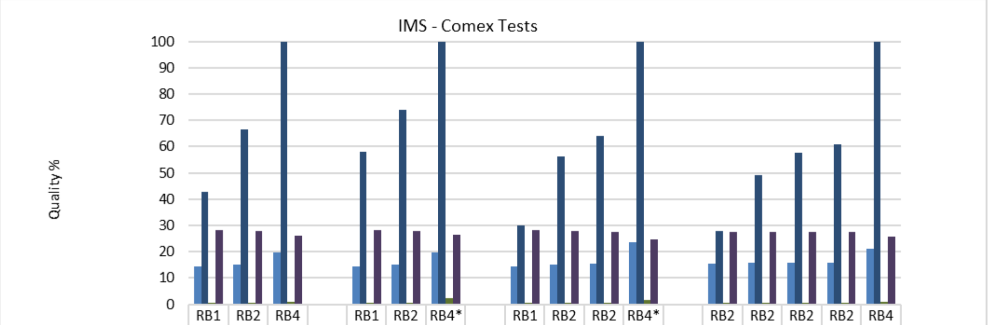
The case study above illustrates that XRT sensor-based sorting technology provides clear business advantages over traditional gravity separation technologies in meeting specific coal product quality requirements. While these benefits may not be fully captured using conventional separation metrics such as EP and Organic Efficiency, XRT sorting proves to be a highly effective solution for coarse fraction sorting at high throughput, particularly when implemented in a modular, parallel configuration.

This next part of the paper will explore the properties of XRT sensor-based sorting, followed by a discussion on a typical plant layout. It will also address common challenges, including material handling and particle surface moisture, and outline optimisation strategies to enhance the performance of XRT sensor sorters in coal applications.

6 Typical properties of sensor sorters

Sensor sorters are highly adjustable machines and can be preset to produce various products, in terms of quality, from the same material. This is illustrated in Fig. 9[‡] where different products are produced from the same source by selecting the required product type from the sorters operating panel.

[‡] In Fig. 9, the * on the RB4 product denotes that the sulphur at that particular yield is out of the required specification and it may be necessary to select a different product (RB1, RB2 or RB3).



	RB1	RB2	RB4	RB1	RB2	RB4*	RB1	RB2	RB2	RB4*	RB2	RB2	RB2	RB2	RB4
Cummulative Ash	14.4	15.2	19.7	14.5	15.2	19.8	14.3	15.1	15.4	23.6	15.4	15.8	15.9	16.0	21.2
Cummulative Yield	42.8	66.5	100.0	58.0	74.2	100.0	30.0	56.3	64.2	100.0	28.0	49.0	57.8	60.7	100.0
Cummulative S	0.6	0.7	1.0	0.6	0.7	2.3	0.6	0.7	0.6	1.8	0.5	0.5	0.6	0.6	0.9
Cummulative CV	28.2	27.9	26.1	28.3	28.0	26.4	28.2	27.8	27.7	24.8	27.6	27.6	27.5	27.5	25.7

Fig. 9. Sorting results demonstrating ability to produce different quality coal products from the same ore

Fig. 10, shows the size fractions and throughputs of coal being treated by various 1m wide sorters in Asia and Europe. Capacities can be increased by installing wider sorters, which can be up to 3m wide, with throughputs generally increasing linearly.

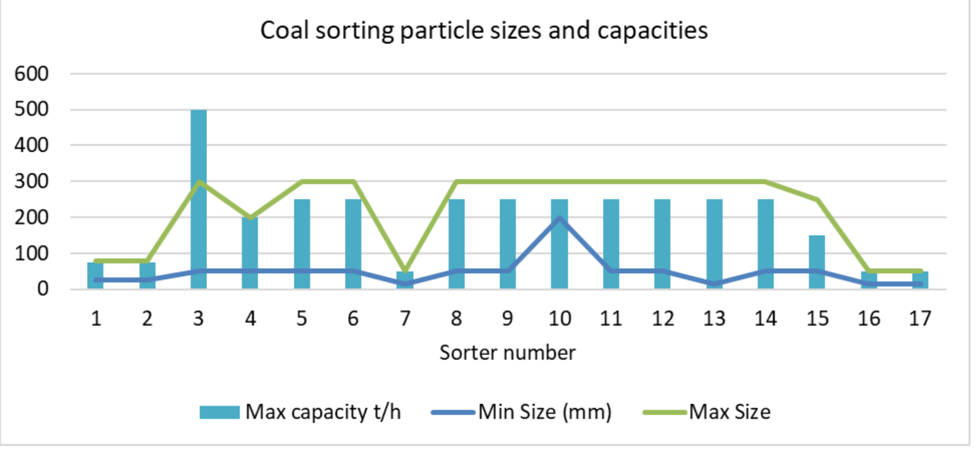


Fig. 10. Size ranges and throughputs of coal being treated in a single 1m wide sorter in Asia and Europe[§]

7 Plant set up

The typical plant set up for a coal sorting process may consist of a single, or multiple stages of comminution and screens to remove fines and to size the coal feed into acceptable size ratios for the sorters. An example of a coal sorting plant is shown in Fig. 12.

In the plant design the particle size distribution (PSD) envelope of the material post the comminution circuit must be considered. This will inform scenario simulations and sizing of

[§] Sorter 3 is a 2m wide sorter, all other sorters are 1m wide the sorting equipment as well as the additional technologies used to beneficiate the finer fraction.

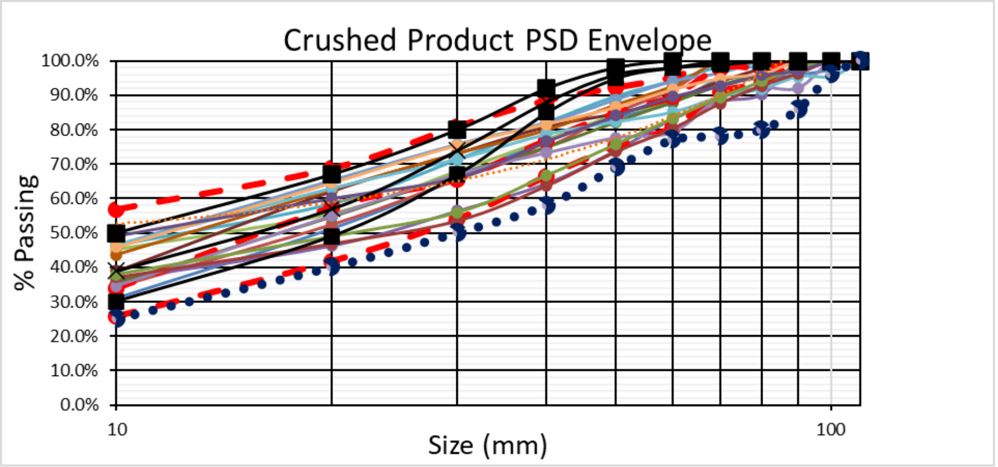


Fig. 11. A consolidation of PSDs of feeds treated by various coal beneficiating plants

For coal, the plants are usually built to treat material of size +20mm and above, the finer fractions may be treated through other technologies such as dense medium separation, wet or dry jigging, spirals and flotation. For diamonds, on the other hand, sorters may treat material down to sizes of approximately 2mm.

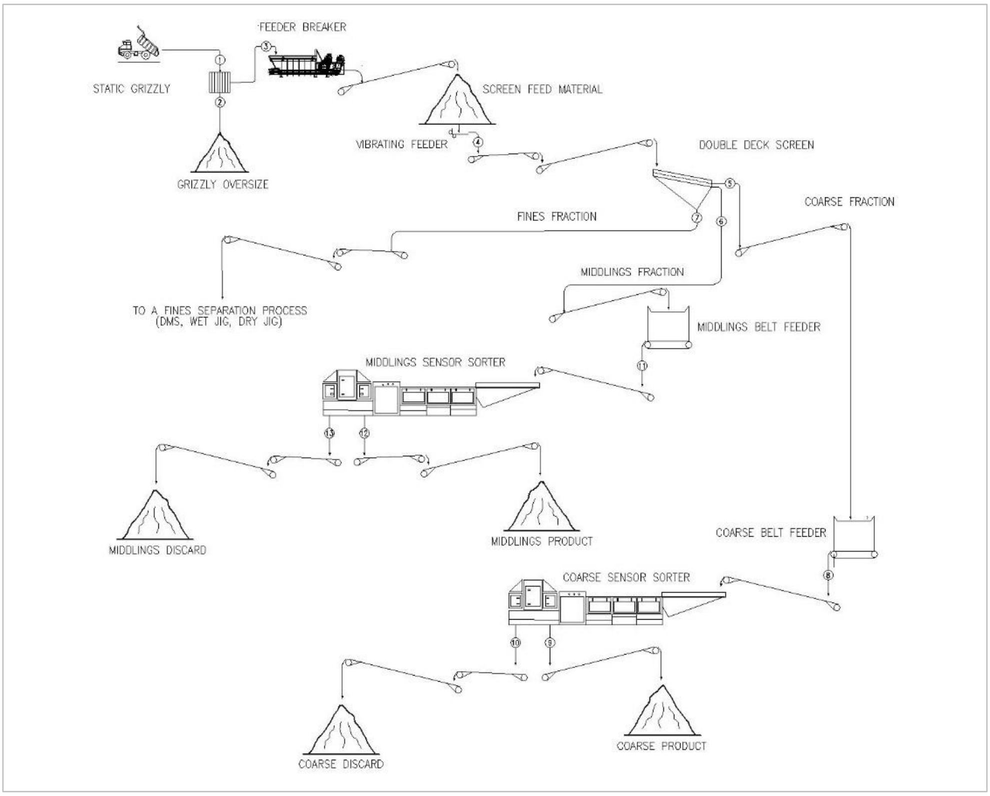


Fig. 12. Example of a coal sorting plant

8 Plant control and monitoring

The sorter's performance can be monitored in conjunction with other plant process parameters on a single monitoring system. Some of the critical measurable parameters on sorters include:

- Belt speed – Must be correct to ensure particles reach valves when they open
- Ejection pressure – Adjusted according to particle size & density
- Ejection rate - Can sometimes be used as a proxy for yield
- Particle size distribution
- Individual valve opening count – Proxy to ensure even feed distribution on the belt
- Belt coverage and throughput

This information is used in conjunction with results from chemical analyses to ensure that the plant is operating efficiently. Examples of dashboard values for the throughput performance, ash and sulphur values, are shown in Fig. 13, Fig. 14, and Fig. 15.

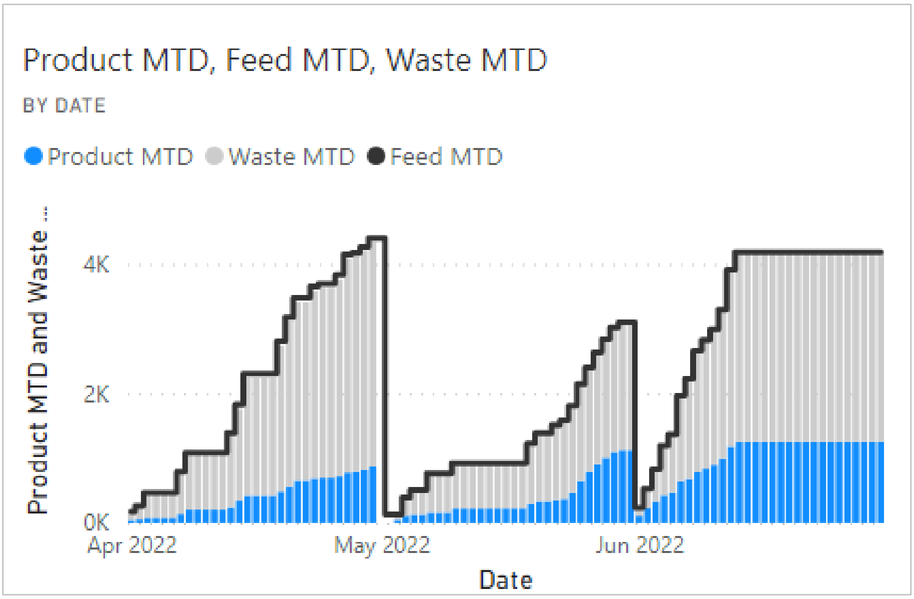


Fig. 13. Example of throughput performance dashboard

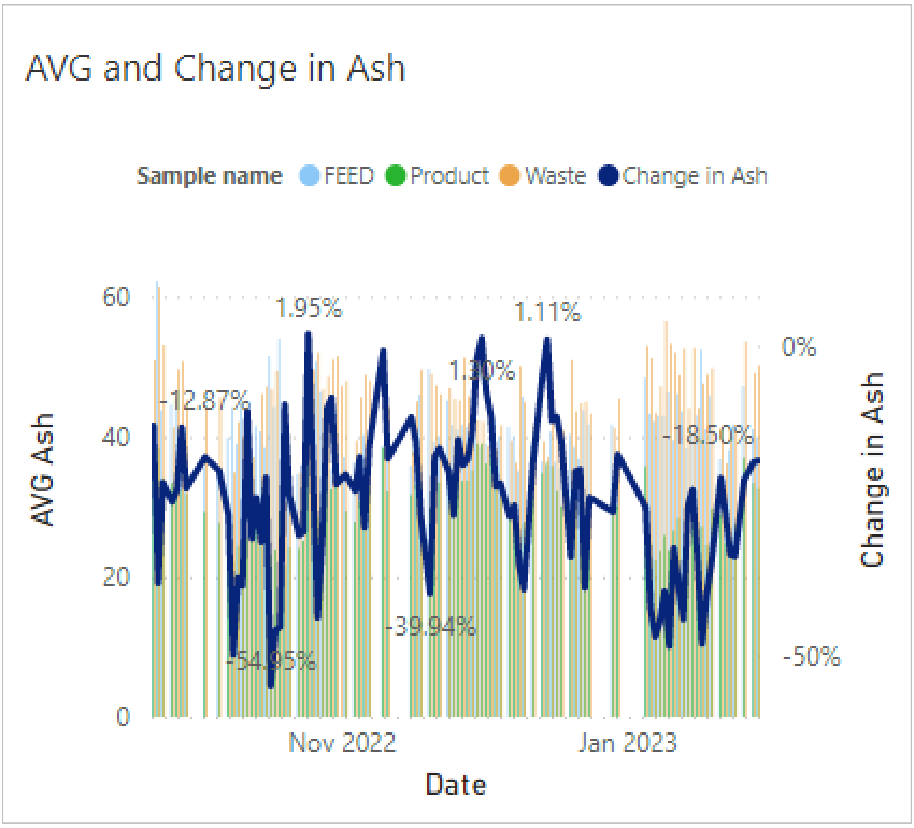


Fig. 14. Example of Ash performance dashboard

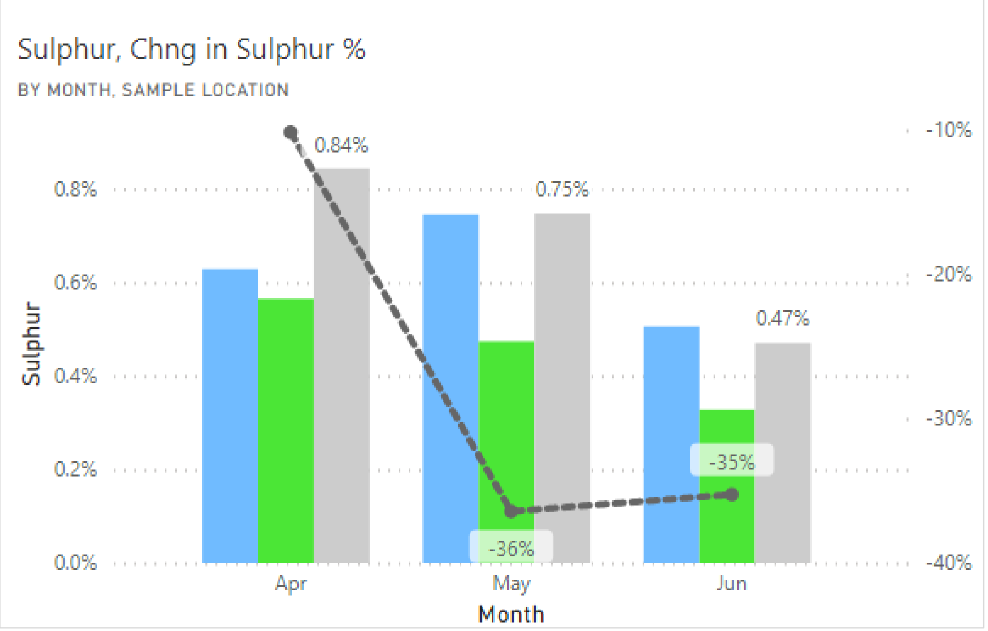


Fig. 15. Example of sulphur performance dashboard

9 Critical success factors

To obtain the best value from an operation that incorporates sorters, the following measures must be implemented:

1. Test the ore to be treated, as far as possible, using samples that represent the material that will be treated over the life of the mine. This will help to incorporate possible variations throughout the project's life in the design and business case. If this is not possible, sorters still have a very high degree of flexibility to cater for changing feed conditions during the project's life
2. End users must involve their geologists/metallurgists during the test work and provide the manufacturer with ore characterization studies. This enhances the quality of the test campaign and will ensure continuity of knowledge throughout the project lifecycle
3. The feed must be prepared and presented to the sorter in line with the manufacturer's recommendations. This typically refers to correct material sizing, avoiding excessive moisture, overfeeding and incorrect feed chute designs
4. Ensure that the operators receive full training before commissioning and for a defined period after plant handover post commissioning.
5. Keep critical spares such as an X-ray tube or colour camera onsite, a spare belt and some valves to reduce downtime in the event of failure, particularly in remote locations where the equipment manufacturer may be a considerable distance away. Sensor sorters are robust machines and X-ray tubes generally last up to two years, or sometimes longer

6. Calibrate the sensor system as recommended, this is typically an automated function, and this should be done in conjunction with an automated valve test which is usually a pre-set feature on sorters
7. Conduct regular inspections on the sorter and the on the equipment surrounding it

10 Conclusions

This paper presented some key aspects that must be considered when the application of sensor sorters is being considered for coal beneficiation. Sensor sorters are robust machines that provide users with simplicity and a high degree of processing flexibility when implemented correctly.

Using a case study, this paper showed that it is possible for a sensor sorter to have a lower EP than a dense medium separator yet produce a higher yield of within specification product, particularly where sulphur removal is factor.

Additional studies are currently underway to enhance the body of knowledge on the current state of the separation efficiency of sorters in coal.

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