

Development of a high capacity, low cut spiral for the coal industry

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Traditional coal spirals typically treat about 2.5 to 3.5 tons per hour (tph) feed solids per start, with a high relative density (RD) cut point of ± 1.6 – 1.8 . In recent years, low cut point spirals were introduced into the coal market. Typical throughputs of about 1.0-2.5 tph solids per start, to prove low RD capabilities, are reported in literature and audits of mines with low RD spirals have shown similar ranges.

Many coal spiral plants have been designed to treat fines contributing 6-10 % of the total plant feed. Audits have shown a drastic increase over the years in the amount of fines reporting to the spirals, with some mines reporting up to 30 % increases. This adds significant pressure onto spiral banks leading to inefficiencies. Replacing the traditional spiral with a low cut spiral, without increasing the number of starts, adds even more pressure to the circuit. Also, given the need for a low cut, and that this comes with significant yield losses, bulk processing of coal with spirals at a low cut point would require the use of significantly more spirals, increasing the required plant footprint. Industry players approached Multotec to look at the design of a high capacity spiral with low RD cut capabilities.

This paper evaluates a new approach: a 3-stage, 4-product, 10-turn spiral with 2 intermediate discard removal points. This arrangement allows for low cuts at high solids percentages and high feed rates, thereby reducing the required plant footprint. Intermediate discard removal results in the ideal percent solids for a low cut at the final stage. A cut point of 1.53 was achieved with good yields at a high capacity. This spiral configuration, with intermediate discard removal, has the added benefit of being able to efficiently wash low quality coal or discard.

INTRODUCTION

Spiral concentrators are widely used in fine coal beneficiation as they offer several advantages that include low operating and capital costs, being simple to operate, low maintenance and high tolerance to variability in feed conditions (Erasmus, et al., 2018).

Fine coal slurry (75 – 3000 μm) is fed to the top of a spiral and gravitates downwards. Particles separate radially across the trough as described by the primary and secondary flow (Matthews *et al.*, 1997). The primary flow is the slurry descending along the inclined portion of the trough. The secondary flow occurs radially across the trough (Holtham, 1990). During their passage through a spiral, particles are subjected to hydrodynamic drag, lift, friction, gravity and centrifugal forces.

In general, the motion of particles depends on the particle properties (size, density and shape), the operating conditions as well as the slurry density and flow rate (Atasoy & Spottiswood, 1995). Spiral design (trough shape, inclination, number of turns) also plays a significant role in particle separation (Holland-Batt, *et al.*, 1984).

Relative Density (RD) Cut

Subasinghe & Kelly (1992) mentioned the RD cut as the relative density of that particle which has an equal chance of reporting to either the product or discard stream. Subasinghe & Kelly (1992) concluded that for small particles, the RD cut is affected by changes in the flow rate and particle size. For large particles, the cut is affected by flow rate and solids concentration and to a lesser extent by the particle size itself.

South African coal mines largely use spirals to clean coal of 2 mm x 0.15 mm in size. In some cases spirals are used to treat feed with a top size of 3 mm. The MX7 model has been used for decades as a spiral of choice for fine coal cleaning, especially for the difficult to clean coal (Klima & Benusa, 2006). The MX7 spiral has a recommended capacity of 2.5-3.5 tph solids. It is mainly in heavy minerals where manufacturers are known to have high capacity spirals that can take up to 9 tph solids per start.

In recent years, low cut spirals were introduced into the coal processing market. It is well known that reducing the flow rate and percentage solids on coal spirals, decreases the RD cut (Arnold *et al.*, 2018). Arnold *et al.* (2018) reported that typical throughputs of these low RD cut spirals are about 1.0-2.5 tph solids per start. Site test-work at a South African coal mine by De Korte (2015), achieved a low RD cut on these spirals at a solids flow rate of 1.3-1.5 tph and it was mentioned that a recommended flow on these spirals would be 1.8-2.5 tph solids. Ramsaywok & Mathumbu (2017) achieved a low RD cut at a solids feed rate of 1.5-2.5 tph. It was also reported that an increase in the RD cut occurs as the feed rate increases.

High Capacity Requirements

Honaker *et al.*, (2007), reported a worldwide survey which showed, that coal preparation plants at that time, 6 % of coal treated was feed to the spiral plant. Enslin (2019), in an audit of South African coal mines, reported a drastic increase over the years in the amount of fines reporting to some spiral banks. In some audits, spiral plants which have been designed to handle 7 % of the total feed to the plant, are now receiving up to 30 % of the total feed (Enslin, 2019). These spirals plants were not designed for this and are constantly under pressure. Replacing the MX7 spirals with low RD cut spirals can place even more pressure on the spiral circuit. In almost all instances the MX7 had to be replaced with the same number of starts as on the low cut spiral. It has been observed that some coal washing plants had to cut on the feed rate to accommodate the additional fine coal and also to achieve a low cut on the spirals. Some mines resort to changes in the desliming cyclone setup, increasing the fines to the cyclone overflow, with the subsequent result of constraining the thickener.

SX10 high capacity, low cut spiral

Aiming for a low RD cut results in significant yield losses. Given that coal is a bulk commodity, whenever there is need for a low cut point, then this requires the use of significantly more spirals, increasing the required plant footprint (Arnold, *et al.*, 2018). The Northern Hemisphere coal mines and plant designers realized the need for low cut spirals and requested Multotec to supply a low RD cut spiral. The plant footprint constraints and capacity issues in some mines led Multotec to develop the high capacity, low RD cut SX10 spiral.

It has been claimed in literature that the motion of slurry reaches steady state after two turns and hence effective separation ceases at this point (Subasinghe & Kelly, 1992). Further studies by Holland-Batt (1995) showed that if minerals are liberated, the mineral recovery does not cease, but the rate of recovery gradually decreases with an increase in the number of turns on the spiral. Holland-Batt (1995) and Klima & Benusa (2006) demonstrated that the addition of repulpers on coal spirals has the added benefit of revitalising separation. For many years, the lack of mathematical models that can accurately predict separation on spirals, has made spiral development more costly due to trial and error. A better understanding of particle transport in recent years has helped manufacturers to design more suitable spirals for specific ores. Due to this, coupled with advances in material of construction, spirals are making it possible to configure the desired pitch, descend angle and number of turns that will abide by the desired separation criteria.

The SX10 is a 10-turn spiral allowing the near dense particles longer retention time for separation. Denser particles (quick to separate from the discard), are removed into the center column after the first four turns, with the remaining clean coal and middlings are subjected to repulping. This is followed by three more turns, another discard removal step, and another repulping stage prior to the final distribution of coal on three more turns before the final splits into clean coal, middlings and discard. Following the removal of the

discard from the first two discard draws, the feed rate and percent solids feeding the final three turns is reduced, approximating the ideal feed solids percentage and feed rates for typical low RD spirals. Collecting the discard into the center column means the working surface diameter of the spiral is not affected by the removed discard and hence allowing for extra capacity. Also, the discard removal into the center column has an added benefit, especially when treating low quality coal or discard. It has large volumes of refuse to be collected, without interfering with the separation of the middlings and the clean coal stream.

EXPERIMENTAL PROCEDURE

Sample preparation

Three different types of samples were sourced from two different collieries in South Africa to be referred to as region A and region B. Approximately 600 kg of spiral feed from region A, 800 kg from region B and 600 kg of discard from region B were made available to Multotec.

Sub-samples were taken for specific gravity of solids (SG) and Particle Size Distribution (PSD) analyses. A pycnometer was used to measure the SG and a sieve shaker was used for PSD analysis. The SG for region A and region B spiral feed samples was measured and found to be 1.52 t/m³ and 1.55 t/m³, respectively. The SG of the Discard sample was 1.67 t/m³.

Particle Size Distribution

The PSD of the material as received is shown in Figure 1.

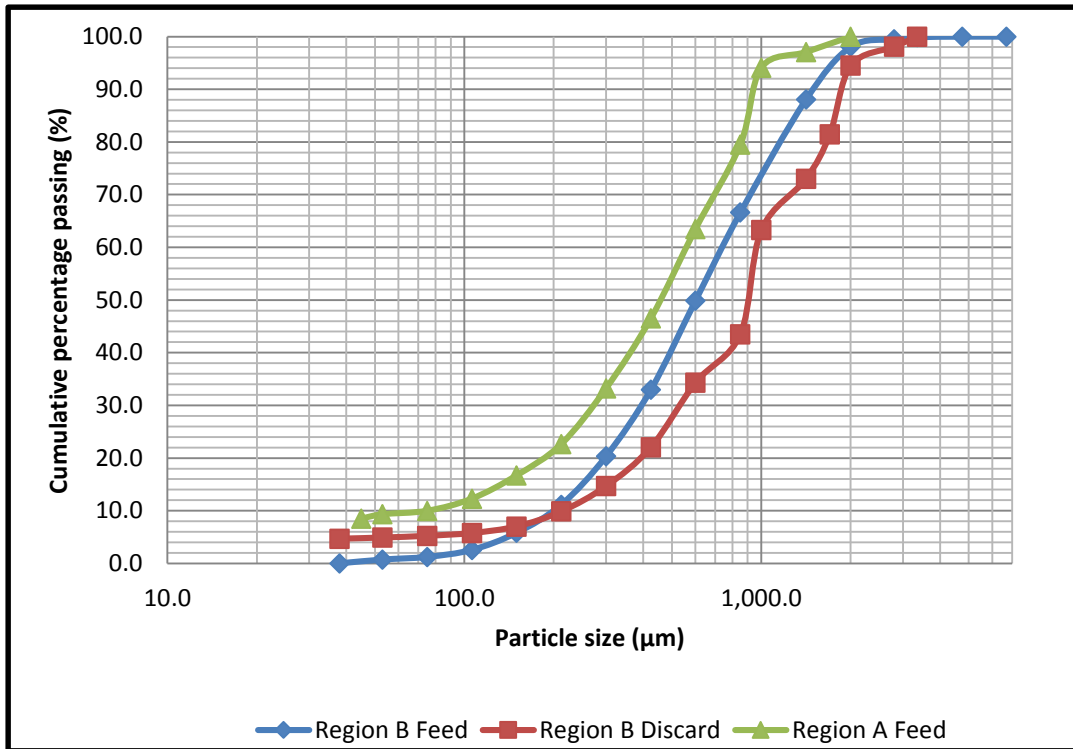


Figure 1: Particle Size Distribution

Figure 1 shows the PSD for region A and B samples. Region A feed appeared to be finer than the region B samples. The region A sample showed a P_{80} of 600 μm while region B samples showed a P_{80} of 1700 and 1200 μm for both discard and the feed samples, respectively. The discard sample demonstrates a coarser PSD as compared to both feed samples.

Spiral Concentrators

The test work was conducted using the Multotec MX7 and SX10 spiral models, which were each fitted with a mouth organ product box as shown in Figure 2.

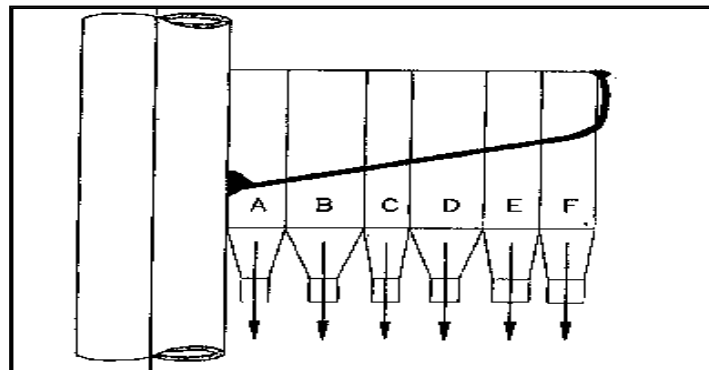


Figure 2: Mouth Organ Fraction

Sample A represents the sample collected from the inside of the trough. It is the heaviest sample and should contain the material with the highest ash content and SG. The product fraction for coal is from the F fraction towards the A fraction, to a chosen point that is still within the product specification. The SX10 has an additional outlet called the auto-reject which is not shown in the figure above. This allows for the immediate removal of high ash content material (discard). The auto-reject outlet discharges into the center column.

Representative samples were mixed with water in order to produce feed solids concentrations as shown in Table 1.

Table 1: Spiral Test Work Parameters for Region A Coal

Spiral Stage	Spiral Model	% Solids by weight (Target)	% Solids by weight (Actual)	Dry solids (tph)	Water (tph)
Secondary	MX7	30	28.5	2.3	5.8
Tertiary	SX10	30	32.9	2.6	5.4

Table 2: Spiral Test Work Parameters for Region B Coal

Spiral Stage	Spiral Model	% Solids by weight (Target)	% Solids by weight (Actual)	Dry solids (tph)	Water (tph)
Secondary	MX7	35	36.6	2.86	4.94
Tertiary	SX10	35	34.7	2.86	5.40
Tertiary	SX10	35	34.0	4.63	8.98
Tertiary	SX10	40	38.4	4.33	6.94
Tertiary	SX10	40	40.5	3.38	4.95
Tertiary	SX10	40	39.9	3.45	5.14

These slurries were fed to the spiral feed box via a distributor with an overflow in order to maintain constant feed conditions during the tests. Figure 3 shows the spiral test rig configuration used for the test work.

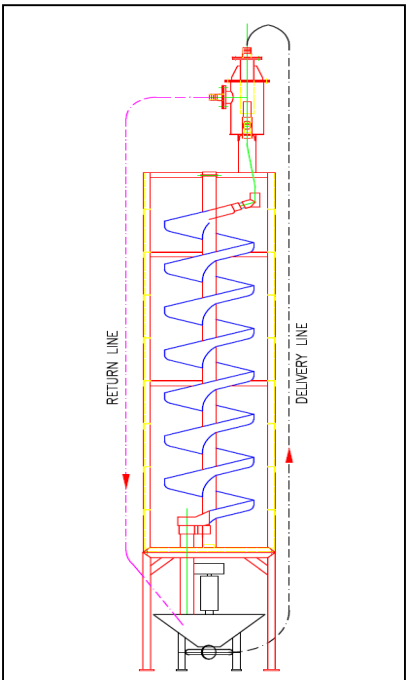


Figure 3: Spiral Test Rig Setup

Each spiral stage was run until steady state conditions were reached before taking the RD measurements at the top of the spiral rig. Three consistent RD measurements and three consistent flow rate measurements were recorded before taking the simultaneous timed samples (Fractions A to F) from the mouth organ product box.

RESULTS AND DISCUSSION

Low cut application: Region A coal

Figure 4 below shows the mass yield comparison between the MX7 and SX10 for Region A.

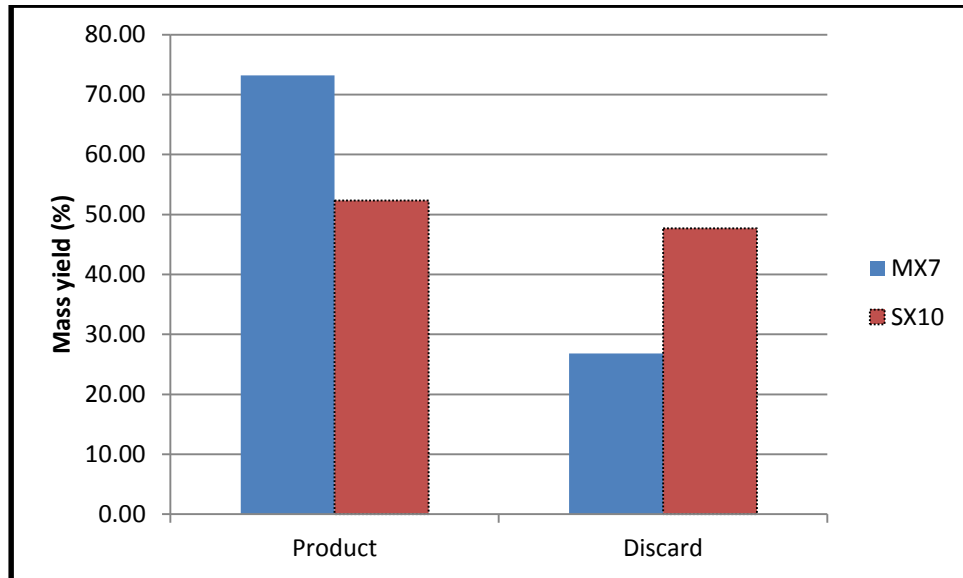


Figure 4: Mass Yield Comparison for Region A Coal

The comparison between the mass yield for the MX7 and SX10 shows the MX7 has a higher mass yield in the product as compared to the SX10. This can be attributed to the intermediate discard removal points, which rejects the material prior to the next stage. The lower mass yield in the product results in a high imperfection (EPM).

Figure 5 shows the percentage ash comparison between the MX7 and SX10 for region A.

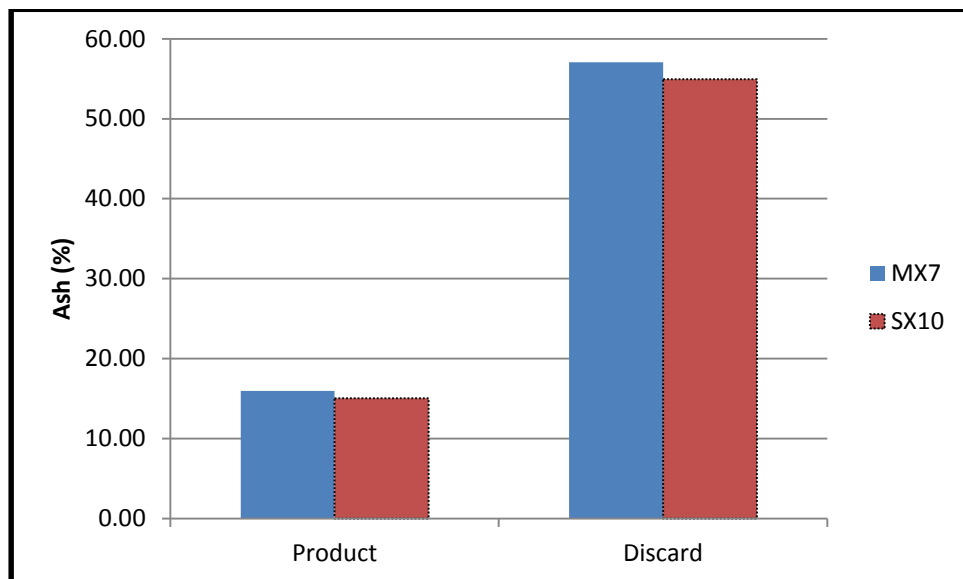


Figure 5: Percentage Ash Comparison Region A Coal

The percentage ash comparison for both spirals show that the MX7 has a higher ash content in the product and discard as compared to the SX10 spiral. The lower ash content in the SX10 can be attributed to the lower mass yield associated with the low cut. Cutting low results in the loss of good quality coal to discard.

Figure 6 shows a Calorific Value (CV) comparison between MX7 and SX10 for region A.

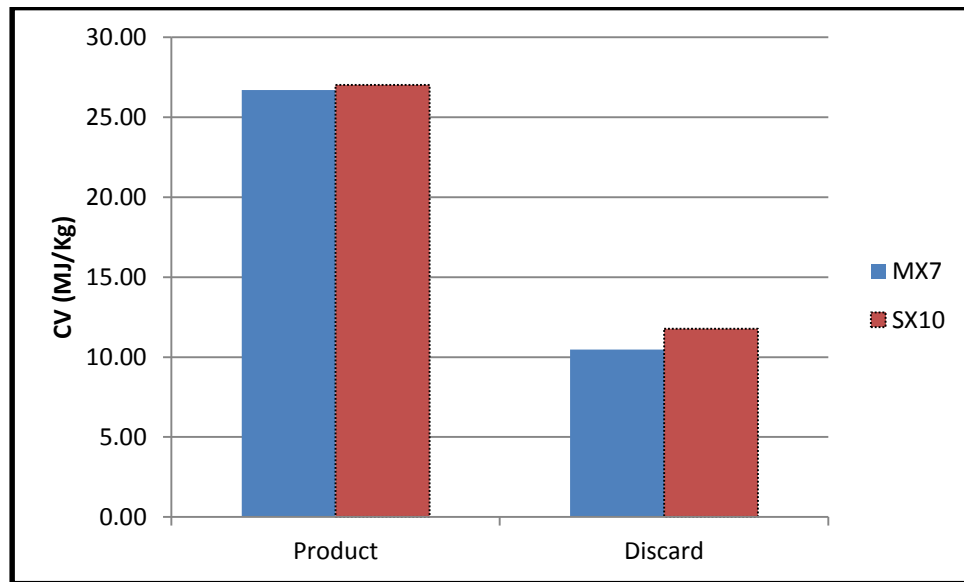


Figure 6: Calorific Value Comparison for Region A Coal

The CV comparison for both spirals shows an additional 1 MJ/kg in the product when using the SX10 in comparison to the MX7 spiral. The CV comparison in the discard shows that there is a higher CV for the SX10 discard as opposed to the MX7.

Figure 7 shows the partition curve comparison for MX7 and SX10 in Region A.

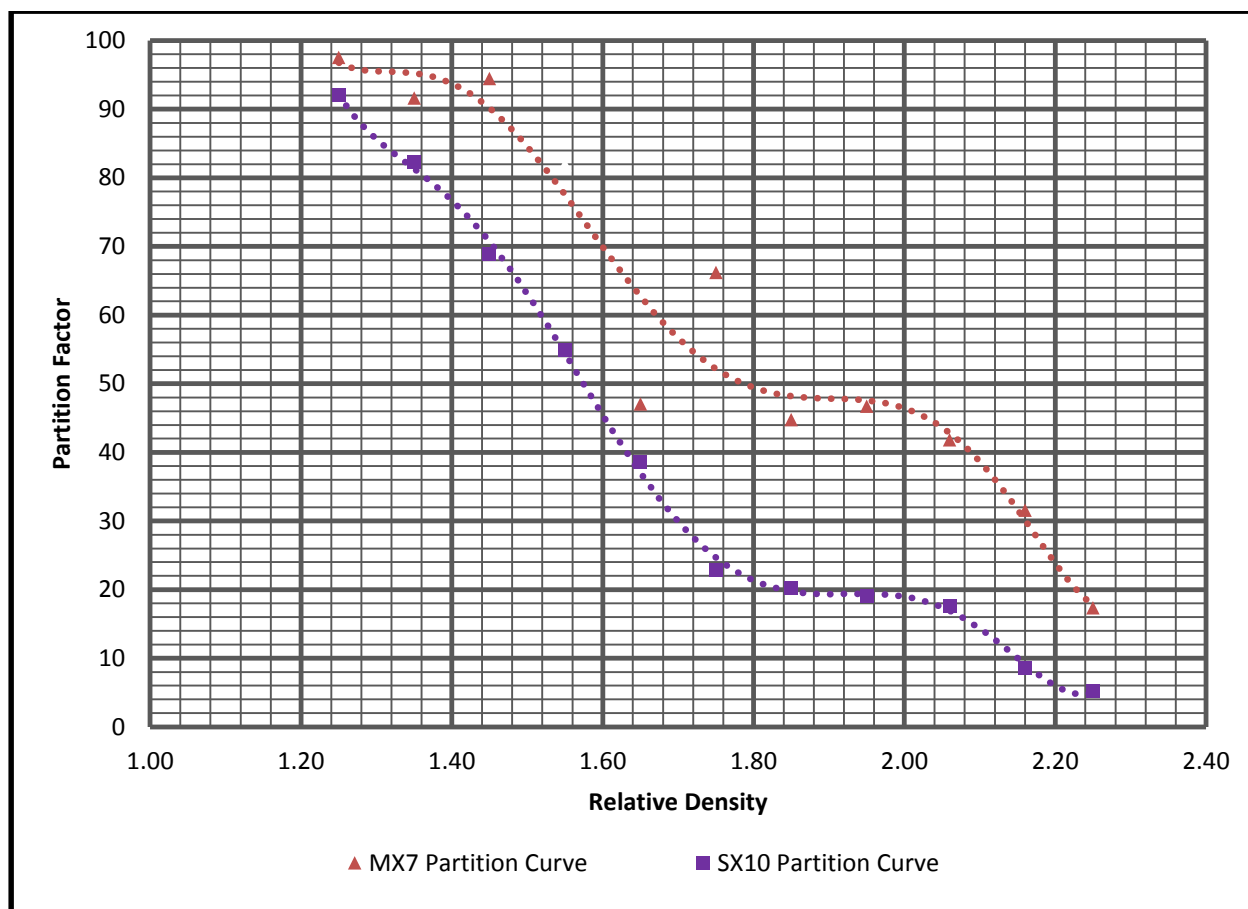


Figure 7: Partition Curves Comparison for Region A Coal

By using curve fitting the SX10 spiral partition curve shows a cut point (D_{50}) of 1.56, whereas the MX7 shows a cut point of 1.78. There is a 0.22 density differential between the cut point for SX10 and MX7 spirals. Both partition curves show that the gradient flattens out between a density of 1.75 and 2.0. This can be due to near density particles which makes separation difficult.

Table 3 shows the efficiency result comparison for region A coal washing on the MX7 and SX10.

Table 3: Efficiency for Region A Coal

Efficiency Test Results		
	MX7	SX10
Feed % Ash	22.23	21.88
Product % Ash	15.96	15.02
Discard % Ash	57.06	54.93
Product Yield	73.21	52.34
D50	1.78	1.56
Ep	0.26	0.165

The MX7 shows that it has a higher Ep value than the SX10 spiral. It is expected that when you cut at a lower density, the Ep value increases which is a result of some misplacement of the product to the discard. The results suggest that a large number of near density material were recovered into the product by the MX7 spiral whereas the SX10 was able to reject the near density material, thus improving the Ep.

Low cut application Region B Coal

Figure 8 shows the mass yield comparison between the MX7 and SX10 for region B.

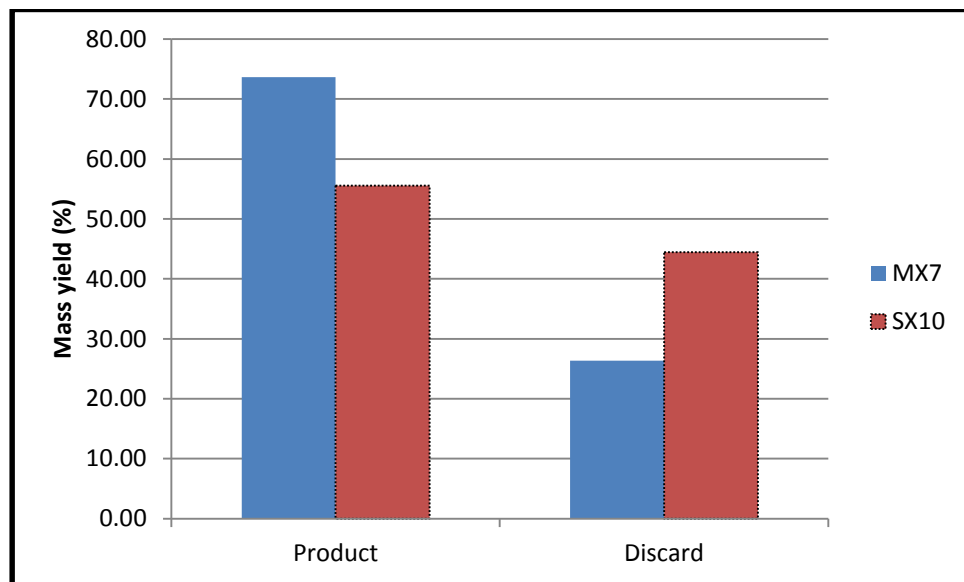


Figure 8: Mass Yield Comparison for Region B Coal

The comparison between the mass yields for both spirals in region B coal shows that the MX7 has a higher mass yield in the product as compared to the SX10. The results also indicate that the SX10 has a higher mass yield in the discard. This behavior was also observed in the region A sample.

Figure 9 shows the percentage ash comparison between the MX7 and SX10 for region B coal.

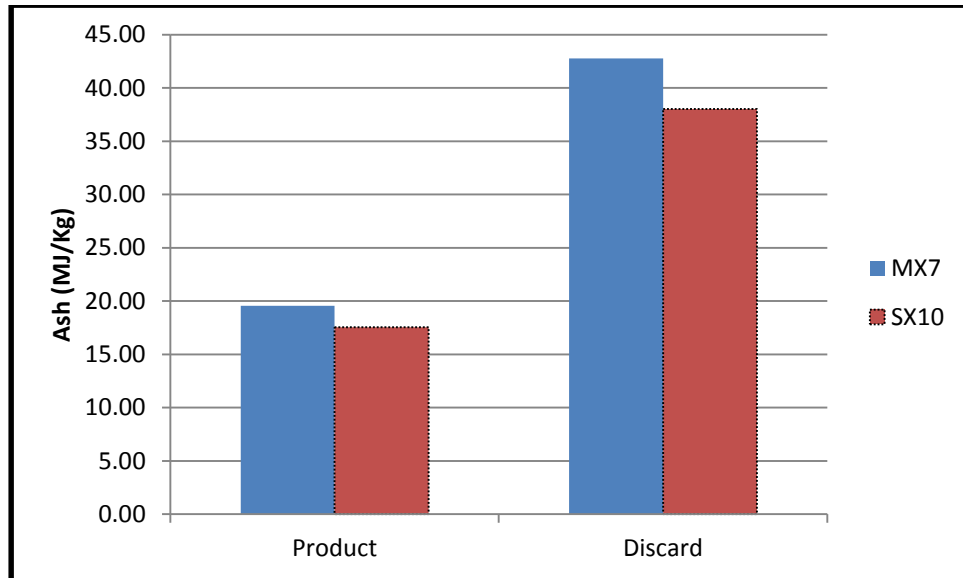


Figure 9: Percentage Ash Comparison for Region B Coal

The ash comparison for both spirals for region B shows that the SX10 yields a 2 % less ash as compared to the MX7 spiral. The SX10 also shows a significant reduction of the ash content in the discard as compared to the MX7. The reduction in the ash content was also observed for the region A sample, but it was not as significant as compared to the region B sample.

Figure 10 below demonstrates the CV comparison between the two spirals for region B.

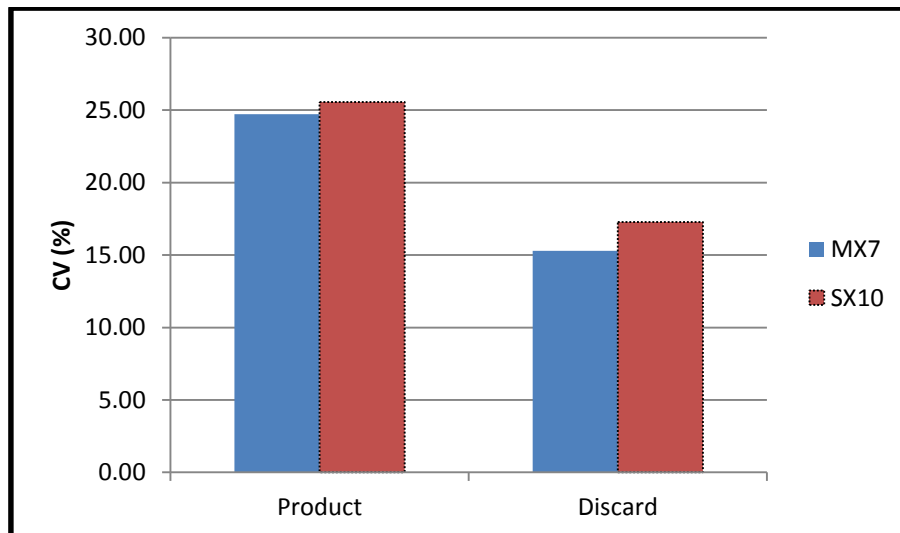


Figure 10: Calorific Value Comparison for Region B Coal

There is an additional 2 MJ/kg CV in the product when using the SX10 on region B coal as compared to the MX7 spiral. There is also a sweeter discard for the SX10 as compared to the MX7.

Figure 11 illustrate the partition curve comparison between the MX7 and SX10 for region B coal.

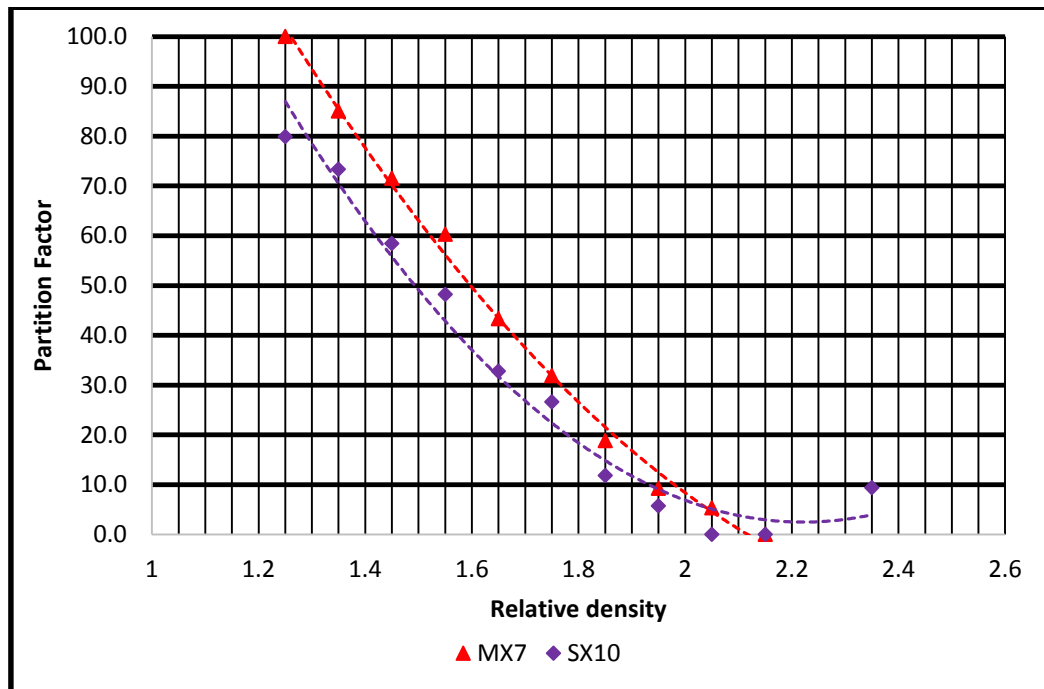


Figure 11: Partition Curves Comparison for Region B

The SX10 spiral partition curve shows a cut point (D_{50}) of 1.53, whereas the MX7 shows a cut point of 1.61 for region B coal. There is a 0.08 density differential for the cut point. This might be due to less near density particles which makes it difficult to clean most of the existing coal ores.

Table 4 shows the efficiency results comparison for region B coal washing on the MX7 and SX10.

Table 4: Efficiency for Region B

Efficiency Test Results		
	MX7	SX10
Feed % Ash	21.74	19.76
Product % Ash	19.02	17.56
Discard % Ash	42.76	38.03
Product Yield	73.2	52.30
D50	1.61	1.53
Ep	0.19	0.22

The MX7 shows a lower Ep value than the SX10 spiral. It is expected that when you cut at lower density the Ep value increases which is a result of a lot of misplacement of good ash material in the discard. This is visible on the SX10 which has a slightly lower cut point.

Throughput evaluation on the SX10 for typical spiral feed treatment

The SX10 spiral was further tested at different throughputs to demonstrate optimum operating parameters.

Figure 12 demonstrates the relationship between the throughput and product mass yield on the SX10 spiral using region B coal.

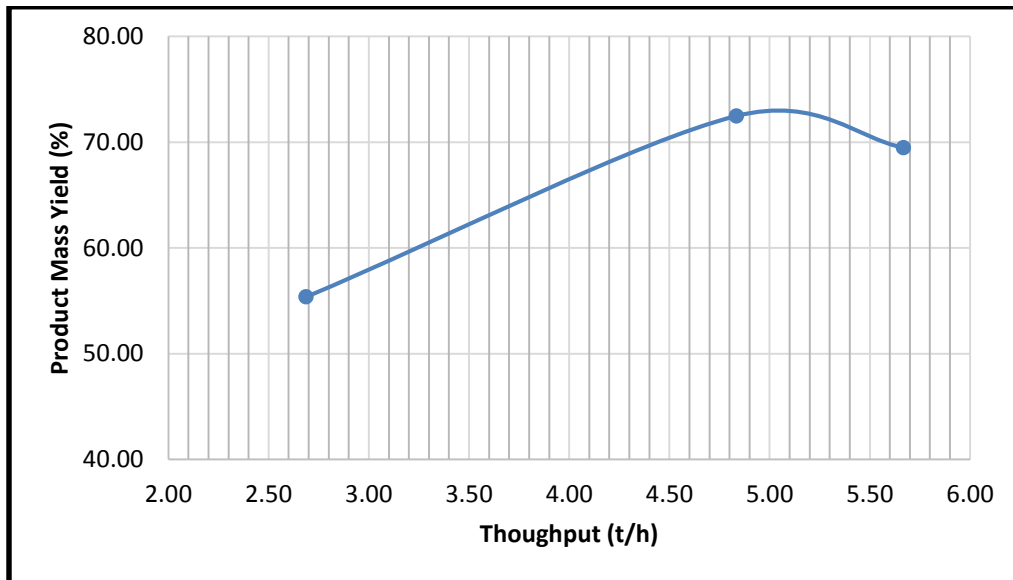


Figure 12: Throughput versus Product Mass Yield

Figure 12 shows that lower throughputs results in lower mass yield. The curve also suggests that the increase in throughput results in the increase in the mass yield to the product up to a throughput of 4.8 t/h. By increasing the throughput further, the mass yield starts to decrease, therefore 4.8 t/h is the optimum throughput for the SX10 spiral.

Figure 13 shows the relationship between the product quality and throughput on the SX10 spiral.

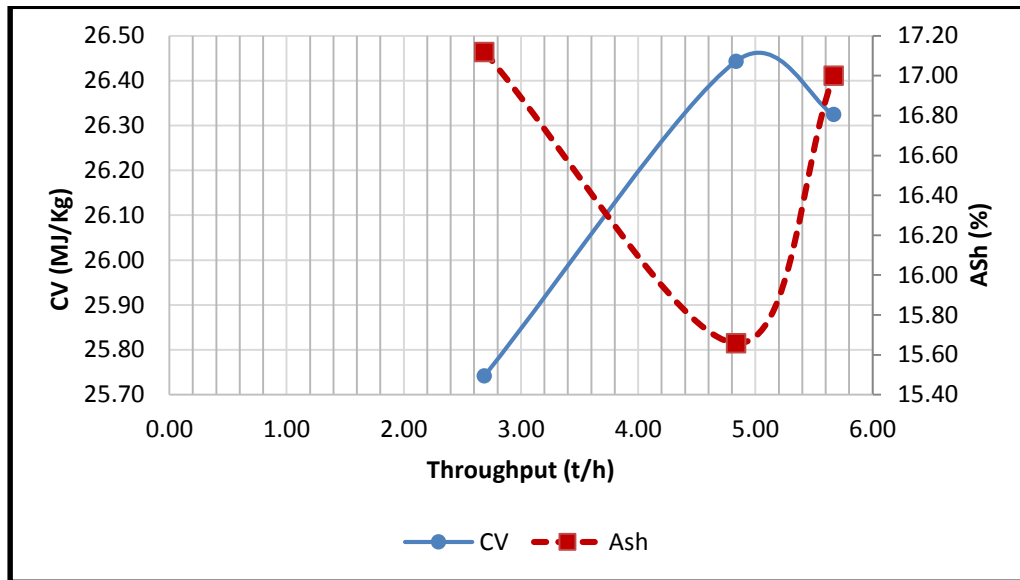


Figure 13: Relationship between Throughput and Product Quality

Figure 13 indicates that increasing the throughput between 2.6 and 5 t/h results in an increased CV and decreased ash value in the product. If the throughput is increased further than 5t/h, the product quality is also affected. The curve suggests that the ash is more sensitive at higher throughput rates, compared to the CV.

Throughput Evaluation on the SX10 for Discard Retreatment

The SX10 was further evaluated for retreatment of a tailings dump. The results obtained are summarized in Figures 14 and 15.

Figure 14 shows the relationship between the product mass yield and throughput on the discard sample.

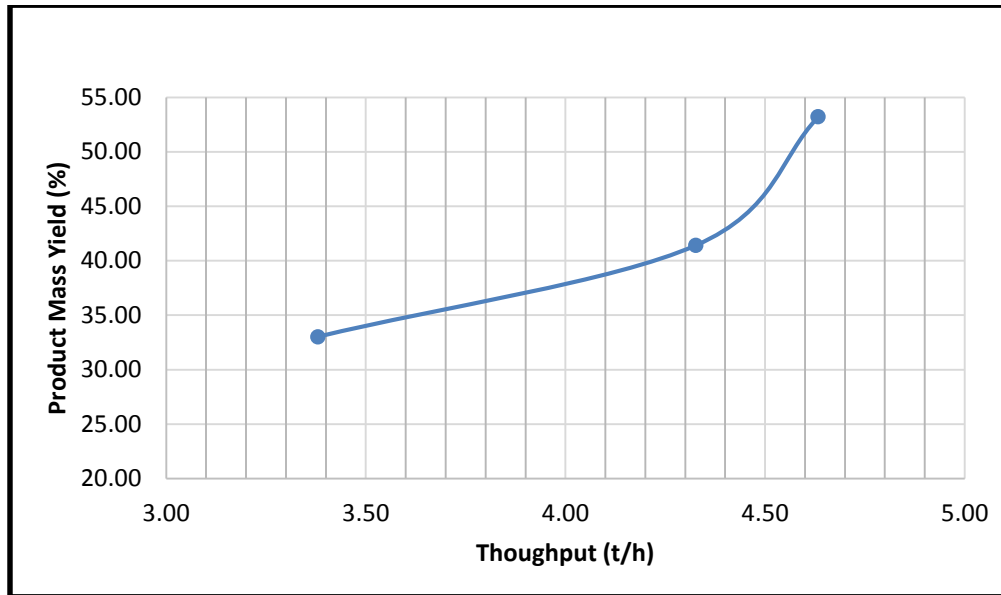


Figure 14: Relationship between Throughput and Mass Yield to Concentrate

The results show that when the throughput is increased on the discard sample, the mass yield to the product increases significantly. It can be observed that there is a constant gradient between a throughput of 3.3 tph and 4.3 tph while between a throughput of 4.3 tph and 4.66 the gradient becomes steeper indicating a massive increase in mass yield.

Figure 15 below shows the relationship between the solids concentration and the mass yield to concentrate.

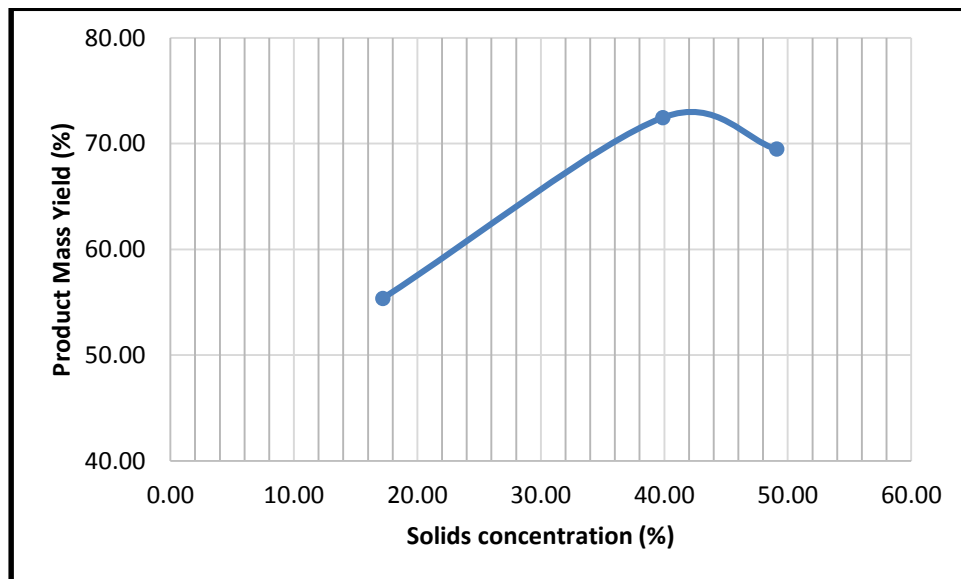


Figure 15: Solids concentration versus Mass Yield to Concentrate

Figure 15 shows that when the solids concentration is increased, the mass yield to the product increases significantly. When the solids concentration is increased further than 40 %, the mass yield decreases. An increase in solids concentration of higher than 40 % results in a decrease in mass yield at a solids concentration.

Figure 16 shows the relationship between throughput and product quality for a typical spiral feed treatment.

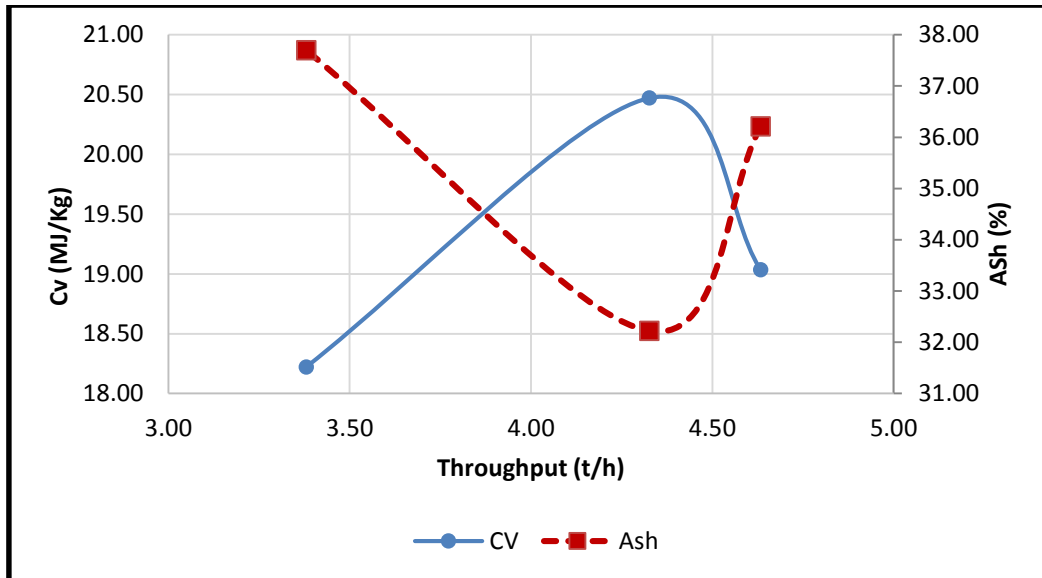


Figure 16: Relationship between Throughput and Product Quality

Figure 16 shows that when the throughput increases, the calorific value also increases up to a throughput of 4.3 tph. By further increasing the throughput, the product quality decreases significantly. The curve suggest that both the CV and ash are sensitive at high throughputs.

CONCLUSION AND RECOMMENDATION

The SX10 spiral shows a lower cut point as compared to the MX7 spiral in both samples. The results also shows better efficiency on region A coal than the MX7 spiral. The MX7 spiral shows a higher mass yield at higher cut densities, while the SX10 shows a lower mass yield at a lower cut density. The results indicates that the spiral can be operated at higher throughputs of about 5tph without compromising product quality when running fresh spiral feed material. It was also observed that the spiral can treat discard at higher throughputs of about 4.3 tph. If the throughput and solids concentration is increased further, the product quality is compromised, especially the ash content.

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