Optimisation of MX7, SX7, SX10, and SX4 coal spirals on South African coal to produce data that can be used to generate a predictive model for spiral performance

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Abstract. Spirals are used in the South African coal industry for the beneficiation of coal in the 0.1 mm to 2 mm range. While some fine coal in the range <1mm and 0.1mmcan be treated using dense medium systems, spirals remain the preferred method in many local operations due to their lower operating costs and simplified design. Multotec coal spirals have been able to produce good product quality with a high calorific value (CV) recovery, while demonstrating high ash and sulphur rejection. These can be used to clean coals that are difficult to wash while providing an enhanced and efficient coal-washing experience due to their compact modular design. Coal washing efficiency, however, is dependent on the spiral operating parameters and there exists optimum operating conditions at which the highest separation efficiency is achieved. The effect of feed solid throughput and solid concentration on mass yield, CV recovery, and ash rejection were studied on four spirals for the purpose of selecting optimal operating conditions. Test work was conducted using coal sample sourced from Emalahleni region on the four xxx spiral concentrators (MX7, SX10, SX7 and SX4 models). For each spiral, sensitivity analyses were conducted by varying solid concentration between 25% and 35%, and feed throughput was between 2 tph and 3.2 tph. Thereafter, the results were compared, and in each case, the optimal operating conditions were selected. While a predictive model is not yet developed, the data and insights generated here form the foundation for future modelling efforts aimed at supporting accurate spiral selection and performance estimation.

1 Introduction

Coal spiral concentrators have commonly been accepted as the equipment of choice for beneficiation of fine coal for many years now, separating high density ash containing discard streams from low density coal particles. These separators exploit the physical properties of the particles and rely of their differential movement under combined effects of gravity, fluid drag, and centrifugal forces [1]. Their separation efficiency depends on a variety of factors,

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including feed particle size distribution (PSD), pulp density, splitter positioning, and the mechanical design of the spiral [2, 3]. Numerous studies have explored the effect of varying operating parameters on product quality, which led to latest improvements such as the high-capacity designs and real-time control strategies [4, 5]. Despite these improvements, maintaining separation efficiency that ensures a consistent product recovery process during fine coal beneficiation remains a challenging task, especially if the conditions present variations both in feed quality and fine coal fractional distribution [6].

The separation dynamics of spiral concentrators is complex; however, mathematical modelling and washability studies have contributed an important role in enhancing our understanding of the performance of such units. Research has demonstrated that the probable error (E_p) and density cut point (d_{50}) are crucial indicators of separation sharpness, with lower E_p values correlating with improved coal recovery and reduced misplaced material [2]. Process control models by Vermaak et al [5], amongst others, have shown that product quality control can be achieved by vigorously manipulating operating parameters. Furthermore, the effect of ultrafine particles on spiral performance has been studied, with findings that excessive slimes negatively affect the separation efficiency of spiral separation [7]. These studies indicate key aspects optimising feed characterisation and operational conditions to enhance maximum clean coal yield while ensuring a high rejection capacity of ash content [8]. However, while these findings have significantly advanced the understanding of spiral separation efficiency, they have largely concentrated on spiral models developed by other original equipment manufacturers (OEMs). In contrast, very limited performance data is available for the specific spiral models under investigation in this study, namely, the SX4, MX7, SX7, and SX10, which are produced by a different OEM.

Very few studies [4, 5], have systematically removed the co-variance that exists among competing variables when evaluating spiral concentrator performance. These works applied controlled experimental designs to isolate and quantify the individual and combined effects of operating parameters—an approach that is often missing in existing literature. Furthermore, P. Ramsaywok and P. Mathumbu [6] adopted a similar approach in the form of a pre-test methodology. Their study aimed to pre-establish the relationship between splitter (or auxiliary cutter) position and ash quality before conducting full test runs. This was performed across two distinct sets of coal spirals sourced from different OEMs, thereby offering a useful baseline for assessing spiral response under controlled conditions.

The influence of feed rate, solids concentration, and splitter positioning on clean coal recovery has been well documented, but the extent to which these findings apply to the specific designs of spirals remains largely unverified [2, 3]. In their feasibility study evaluating the efficiency of fine coal washing using gravity separation methods, Modiga et al [9], employed a coal spiral concentrator in a rougher/cleaner stage configuration and compared its performance to that of heavy liquid separation (HLS) and a reflux classifier. While their findings contribute valuable insights, the study does not clearly specify which spiral model was utilised, nor whether the test work conditions were optimised based on experimental calibration or simply adopted from general industry standards. This limits the ability to draw precise performance comparisons or reproduce the test outcomes across similar equipment.

Therefore, the aim of this paper is to establish the optimal operating conditions for four coal spiral models from the OEM under varying feed rates and solids concentrations. The optimal operating conditions identified in this study provide a structured framework for selecting the most suitable OEM spiral model for specific coal feed characteristics. These findings will form the basis for subsequent work aimed at developing a predictive performance model to support spiral selection and performance estimation. By building on these results, future research can focus on establishing equipment-specific parameters such

as probable error (Ep) and density cut-point (d_{50}), ultimately enhancing process design and operational decision-making.

2 Literature review

2.1 Coal spiral concentrators and their Importance in coal beneficiation

Spirals are used in the South African coal industry for the beneficiation of coal in the 0.1 mm to 2 mm range. While some fine coal in the range <1mm and 0.1mm can be treated using dense medium systems, spirals remain the preferred method in many local operations due to their lower operating costs and simplified design [10].

At these typical size range, coal spirals have been widely used for separating fine coal from ash containing gangue particles due to relative ease of operation which requires minimal operating costs [1-4,]. However, if a spiral concentrator is not properly maintained and operated in line with its design as a true film concentrator, with clean, smooth surfaces and consistent flow conditions, its performance can deteriorate significantly. Poor operational practices can lead to serious inefficiencies, including increased operating costs and substantial opportunity losses due to misplacement of valuable product and deterioration in final product quality. These spirals operate on the principle of density differential, and settling velocities, with finer, denser particles concentrating towards the inner side of the spiral, while the larger, lighter particles migrate towards the outside of the spiral trough [1]. The separation efficiency of spiral concentrators is influenced by a range of factors, including feed type, particle size distribution (PSD), operating conditions, spiral surface condition, and geometric design. These variables have been the subject of numerous prior studies [1-4, 10], each highlighting their critical role in achieving effective separation. .

2.2 Operating conditions for coal spirals

Various studies have investigated the effect of feed rate, pulp density, splitter settings and pitch angle on coal spiral performance, particularly, on separation efficiency and product quality [2, 3, 6, 9,]. Das et al [2] conducted a mathematical modelling study on coal spirals and found that an optimal solids concentration range of 30-35% (w/w) is required to achieve better separation in terms of minimising the amount of coal being misplaced to the discard streams. Similarly, Kapur and Meloy [3] demonstrated the importance of controlling feed velocity and of optimising splitter settings during spiral processing to ensure a clean coal yield of acceptable quality is maintained.

The importance of maintaining laminar flow is critical to achieve optimal spiral performance [8]. This finding is well corroborated by Loveday and Cilliers [6], who on their computational fluid flow studies, developed models that could predict the movement and interaction of coal particles within the spirals. Their key findings highlighted that the separation interface could shift depending on the feed conditions as well as spiral design, greatly affecting product quality.

As mentioned by Arnold et al. [11], low cut point spiral concentrators are typically operated at solids throughputs ranging between 1.0 and 2.5 tph per start, enabling effective separation at lower relative densities. This is further corroborated by De Korte [12], who, in a study conducted at a South African coal mine, demonstrated that low RD cut points were achieved at feed rates between 1.3 and 1.5 tph per start, with optimal operating conditions generally observed within the 1.8 to 2.5 tph range of dry solids. These findings provide a

practical baseline for evaluating the performance of low RD spiral models under industrial conditions, particularly when targeting low-ash, export-grade coal production.

2.3 Washability analysis and separation efficiency

Various coal types exhibit different feed properties and therefore washability studies are critical in assessing the feasibility of producing a clean coal product using spiral to meet specific process requirements. These studies involve densimetric analysis to fractionate the feed into sink and floats at different density cut points [8]. Separation efficiency is often measured using probable error (E_p) and cut point (d_{50}), both of which are indicators of sharpness of separation with a lower E_p value signifying a more efficient separation [2]. A study by Das et al [2], highlighted that an E_p value below 0.10 is ideal for achieving a high-quality coal product, while larger values indicate a large amount of misplaced coal product to the discard stream, effectively rendering separation to be very poor. Although Das et al. [2] highlight that an Ep value below 0.10 is ideal for efficient separation and that elevated Ep values typically indicate increased misplacement of coal product due to turbulence and suboptimal flow conditions, this phenomenon must also be contextualised in terms of coal characteristics and the fundamental separation mechanism of spiral concentrators. Spiral concentrators are not strictly densimetric devices and are therefore inherently prone to higher Ep values, especially when processing coal types with more complex or less favourable physical properties.

This is supported by findings from de Korte [13], who reported that while spirals can produce export-grade product from high-quality seams such as the No. 2 seam of the Witbank coalfield, their performance deteriorates significantly when treating lower-grade coal, such as that from the No. 4 seam, which contains predominantly dull to dull-lustrous coal. The poorer separation observed in such cases cannot be attributed to turbulence or flow dynamics alone but is also a function of the coal's mineralogical and petrographic composition, which affects its response to gravity-based separation.

Therefore, the elevated Ep values observed in the work by Das [2] are not only symptomatic of operational inefficiencies such as turbulence but also reflect fundamental limitations in the spiral's ability to clean certain coal types, as corroborated by both de Korte [13] findings and Coaltech research [10]. This reinforces the importance of considering coal characteristics, not just operating parameters, when interpreting spiral separation performance.

The d_{50} is another important separation parameter in coal spirals. It represents a density cut point at which a coal particle has an equal probability of either reporting to the floats or sinks, i.e. either to the product or discard stream [2]. Holland-Batt [8] highlighted the need to adjust the feed operating parameters to ensure an adequate d_{50} is maintained. Additionally, Ramsaywok and Mathumbu [6] conducted a study comparing a low cut spiral and a conventional spiral used in South African coal industry. Their findings revealed that the low cut spiral achieved a low relative density (RD) cut point compared to the conventional spiral yielding a cleaner quality product, however this was achieved at a lower mass yield, prompting for the trade-off balance between product quality and yield requirements.

2.4 Separation efficiency of a spiral concentrator

The work by P. Ramsaywok and P. Mathumbu [6] effectively demonstrates that separation efficiency in spiral concentrators is governed by the degree of divergence between ash and non-ash recovery curves. A broader gap between these curves corresponds to higher separation efficiency, which typically increases with cumulative mass yield, peaks at an optimal point, and then declines. This concept is important, because it can be used in research

where the outcome does not necessarily target fixed ash values or associated mass yields. The concept supports the use of separation efficiency profiles as a practical means to infer optimal operating conditions, avoiding the constraints of fixed product ash or yield specifications, because this is dependent on ore type and quality of coal being used.

2.5 Latest spiral developments and innovations

An enhanced Holland-Batt spline was used to fine tune spiral performance prediction models successfully and offered improved accuracy in systematically setting up operational parameters [5]. Baloyi and Tjabadi [14] conducted a study on the high-capacity low-cut spiral recently developed by Multotec for achieving density cut points lower than a d_{50} of 1.60. Partition curves were generated from float-and-sink analyses to evaluate the SX10 and MX7 spirals on two South African coal types. The SX10 achieved lower d_{50} cut-points of 1.55 for Coal A and 1.45 for Coal B, as compared to the MX7, which recorded d_{50} values of approximately 1.80 (Coal A) and 1.82 g/cm³ (Coal B). These results confirm the SX10's superior performance in low-density coal recovery applications relative to the MX7.

Process control interventions have also been developed in which a simple process control model was developed by Vermaak et al [5] for spiral concentrators. This development was prompted by the realisation of fluctuating feed conditions, which required product grade and recovery to be stabilized. Their study facilitated real-time control of operating parameters using an optical technology to assess the mineral-gangue interface, ensuring that consistency in spiral performance is maintained to improve overall plant efficiency. According to Vermaak et al [5], the model was tested on an industrial heavy minerals sample, from which no mineral-gangue interface could be detected optically due to the presence of slimes. Furthermore, Casteel [15] explored how new spiral configurations could influence recovery of ultra-fine coal, a research area which remains a challenge today.

3 Experimental procedures

3.1 Sample Preparation

Approximately 10 tons of sample was received for test work from a mine operating in the Emalahleni Region of Mpumalanga Province, South Africa. The sample as received was sun dried and then screened at 2mm. The +2mm size fraction was crushed to 100% - 2mm and blended with natural -2mm fraction. The sample was blended and split into representative sub-samples which are manageable for testwork. Each batch of testwork requires approximately 200kg if desliming is required.

A sub-sample was taken for specific gravity (SG) and particle size distribution (PSD) analyses. The SG was determined to be 1.60 t/m^3 using a pycnometer. The feed sample had a top size of 2mm with a P_{90} of 1180 µm and the percentage passing 106 µm was found to be 18.4% which required desliming to remove the slimes content prior to spiral concentration The sample was deslimed using a Multotec VV165 cyclone which was setup in a test rig configuration as shown in Fig. ***1***.

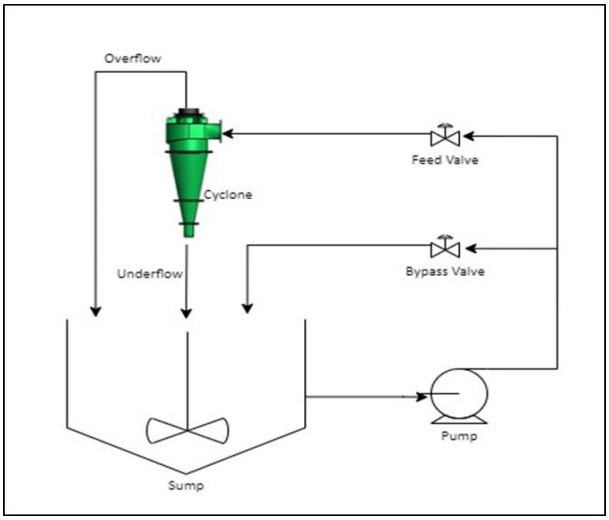

Fig. 1. Test rig setup for desliming

Desliming cyclone test work, as illustrated in Figure 1, was conducted in a closed-circuit configuration with the feed pulp density adjusted to the desired setpoint. Flexible hoses were attached to both the cyclone overflow elbow and the underflow spigot to facilitate sampling. Once steady-state conditions were achieved, both the overflow and underflow streams were redirected into designated collection containers. Each collection cycle continued until the sump was emptied, after which a new test run was initiated following the same procedure. Flow rates for both streams were measured by timing the collection, which also supported the development of accurate mass balances. Collected samples were initially weighed in their wet state, then oven-dried and prepared for particle size distribution (PSD) and for chemical analysis.

Two operating parameters were tested on 4 large diameter coal spiral concentrators, namely, the MX7, SX10, SX7 and SX4 models. These parameters are the solids concentration (%) and throughput (tph). The above spiral models differ slightly in their design and therefore are expected to give varying performance, and can be set up in a single, twin or triple start configuration in a plant environment. Both the MX7 and SX7 are 7-turn spirals fitted with and intermediate re-pulper, while the SX10 is a 10-turn low density cut-point spiral fitted with 2 re-pulpers. The SX4 is a 4-turn spiral with no re-pulper.

The testwork program was setup into two phases: Phase IA focused on the effect of solids concentration on product quality keeping the solids throughput constant, while phase IB focused on the effect of throughput on product quality keeping the solids concentration constant. The optimum % solids (w/w) obtained in phase IA, was used in phase IB to obtain optimum throughput. The testwork matrix for the entire campaign is shown in Table 1.

Table 1: Testwork matrix for the entire campaign

	Phase IA: Effect of % solids		**Phase IB: Effect of throughput (tph)**	
Spiral Model	**% Solids concentration (w/w)**	**Throughput (tph)**	**% Solids concentration (w/w)**	**Throughput (tph)**
MX7	25	2.5	From phase IA	2.0
	30			2.6
	35			2.8
				3.2
SX7	25	2.5	From phase IA	2.0
	30			2.6
	35			2.8
				3.2
SX4	25	2.5	From phase IA	2.0
	30			2.6
	35			2.8
				3.2
SX10	25	2.5	From phase 1A	2.0
	30			2.6
	35			2.8
	40			3.2

3.2 Spiral test work

Representative samples were mixed with water to produce feed solids concentrations as set out in Table 1 above, using an appropriate orifice size in the gravity distributor outlet to ensure a desirable throughput and volumetric flowrates are achieved. The slurry mentioned was then fed to the spiral feed box via a gravity distributor with an overflow to ensure constant feed conditions during testwork. Fig. ***2*** shows the spiral test rig configuration used for the test work.

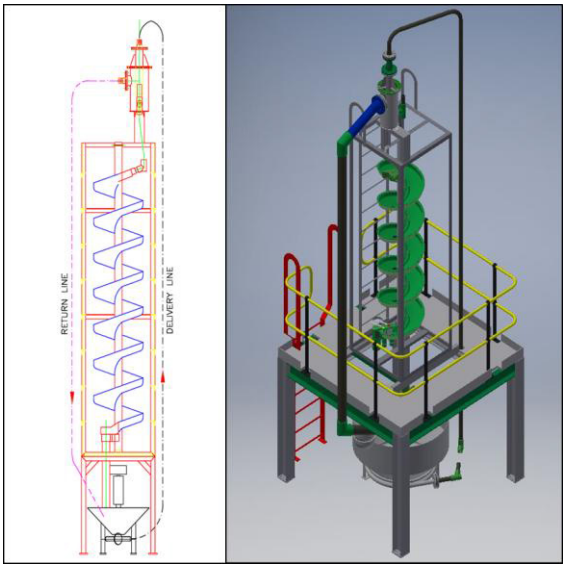

Fig. 2. Testrig setup for spiral testwork

The procedure followed is a batch procedure, and each spiral stage was run until steady state conditions were reached before taking the relative density (RD) measurements at the inlet of the spiral distributor. Three consistent consecutive RD and flowrate measurements were recorded before taking the simultaneous timed samples (Fractions A to F) from the mouth organ product box, except for the SX10 spiral where timed samples were taken from fraction A to G simultaneously.

The mouth organ product boxes used for the testwork are shown in Fig. ***3***. Moreover, the SX7 and SX10 spirals have an extra collection point through the centre column because of the auto-reject (AR) gully fitted on the re-pulper on the 4th turn which redirects some of the discard ash through the centre column and collected as AR fraction at the bottom of the spiral.

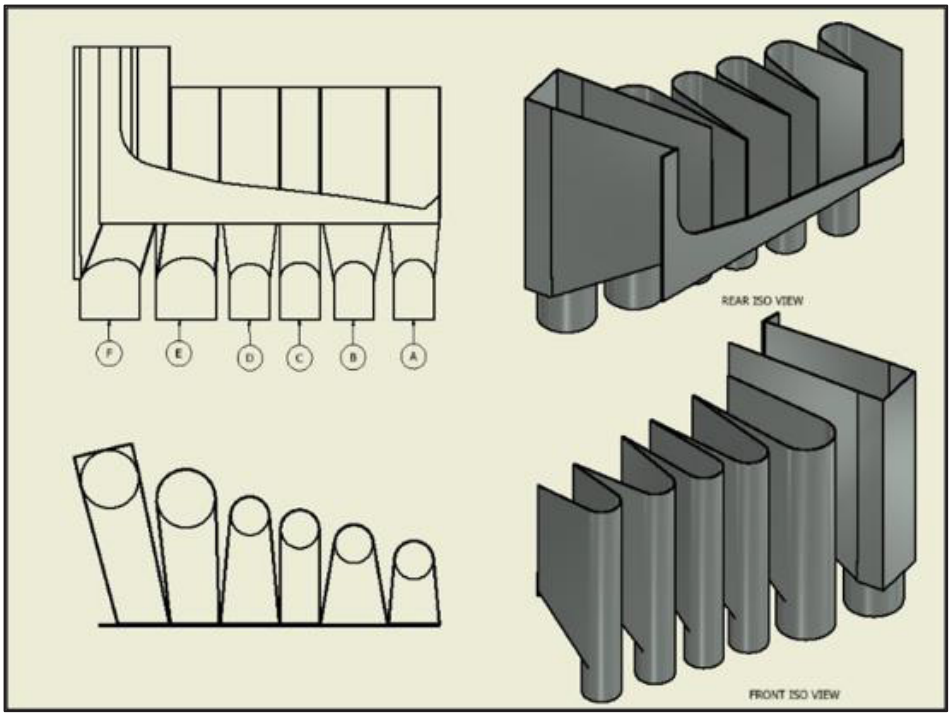

Fig. 3. Mouth organ product box used for sample collection

Final sample preparation process includes weighing the wet samples, filtering and drying, and weighing the dry samples before splitting a representative sub-sample of each for ash and CV analysis in this study, but also for washability analysis in the subsequent phase 2 study which is to follow. Coal separates towards the outside of the spiral, i.e., towards F or G in the case of the SX10, while the ash discard stream concentrates towards the centre column, i.e., towards the A fraction of the mouth organ because of its heavier SG compared to coal. Therefore, once the analysis of each mouth organ fraction has been determined, the mass and its corresponding quality value are cumulated to the product fraction, to generate ash and CV grade and recovery profiles.

4 Results and discussion

4.1 Feed characterisation

Fig. *4* below shows the particle size distribution (PSD) of the feed sample before and after desliming.

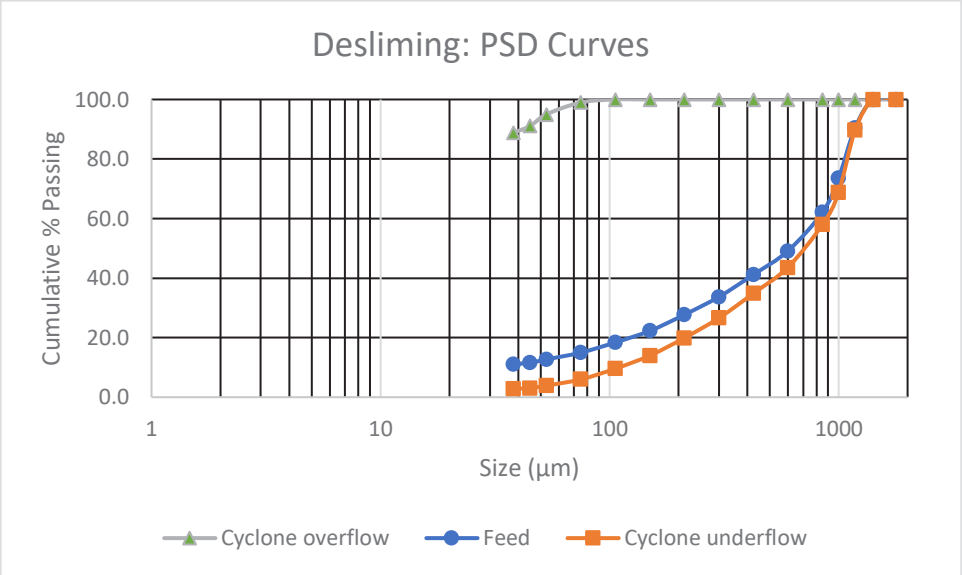

Fig. 4.: Feed before and after desliming

The feed sample had a top size of 2 mm with a P_{90} of 1180 µm and the percentage passing 106 µm was found to be 18.4% before desliming and 9.6% after desliming. Desliming is required to improve separation if the feed contains more than 10% passing 106 µm material for coal application.

Table 2. The washability data shows that a theoretical yield of 42% can be achieved at a density cut point of 1.60, improving the quality of the feed from 39.6% ash to 15.8% ash, while CV is upgraded from 17.4 MJ/kg to 27.8 MJ/kg in the final product.

Table 2: Washability data of the spiral feed sample (Sample from Emalahleni Region)

2.00 + 106 µm			**Fraction**			**Cumulative**		
Sink		**Float**	**Wt. (%)**	**Ash (%)**	**CV (MJ/kg)**	**Wt. (%)**	**Ash (%)**	**CV (MJ/kg)**
	x	1.40	11.4	6.3	30.8	11.4	6.3	30.8
1.40	x	1.50	20.0	12.6	28.3	31.3	10.3	29.2
1.50	x	1.60	10.7	23.0	23.8	42.0	13.5	27.8
1.60	x	1.70	9.9	25.4	22.2	52.0	15.8	26.7
1.70	x	1.80	4.4	37.1	17.8	56.4	17.5	26.0
1.80	x	1.90	3.4	45.5	14.5	59.8	19.1	25.4
1.90	x	2.00	2.1	51.4	12.5	61.9	20.2	24.9
2.00	x	2.10	8.5	54.6	10.5	70.3	24.3	23.2
2.10	x	2.20	3.6	65.6	6.3	73.9	26.3	22.4
2.20	x		26.1	77.2	3.2	100.0	39.6	17.4
			100.0	**39.6**	**17.4**			

4.2 Phase IA: Effect of % solids concentration on product quality

A definition of a few terms is important for the purposes of the discussion below, i.e., ash recovery and CV recovery. Ash recovery is the percentage of total ash (mineral matter) in the feed coal that is recovered to the product stream during separation. High ash recovery indicates that a large portion of mineral matter is reporting to the product stream, this is typically undesirable. On the other hand, low ash recovery is preferred, as it means that more ash has been rejected (i.e., sent to discard), resulting in a cleaner, higher-quality coal product. CV recovery reflects how much of the high-energy (carbon-rich) fraction is recovered to the product stream. Improving CV recovery generally means that more of the carbonaceous material is being successfully concentrated.

Together, ash recovery and CV recovery are used alongside mass yield to evaluate the efficiency of separation and the quality of the coal product. These definitions align with the separation principles explained by Ramsaywok and Mathumbu (2017), where recovery curves are used to assess separation performance.

Figure 5 illustrates the relationship between mass yield, cumulative ash recovery, and cumulative calorific value (CV) recovery for the MX7 spiral at different % solids conditions (25%, 30%, and 35%). Both ash and CV are recovered in the product stream, and the curves reflect the trade-offs between product quality and yield. While the 35% solids condition results in the lowest ash recovery and highest CV recovery, indicating better product quality, this condition approaches the upper limit of the MX7's recommended operating range, and may pose operational challenges. Conversely, the 25% solids condition leads to higher ash recovery and lower CV recovery, making it the least favourable of the three options in terms of separation efficiency. The 30% solids condition presents a balance between yield and product quality, suggesting it may offer the most practical operating point for optimizing spiral performance within acceptable process limits.

Similarly, for the SX7 spiral in Fig. ***6***, 30% to 35% solids concentration provides the best separation efficiency. with the results showing that the highest CV recovery and low ash recovery is achieved at 35% solids concentration, while at higher mass yield of more than 50%, the solids concentration at 30% achieves the lowest ash recovered to the product. The lowest CV recovery and higher ash recovery was achieved at 25% solids concentration making this choice undesirable for optimum conditions.

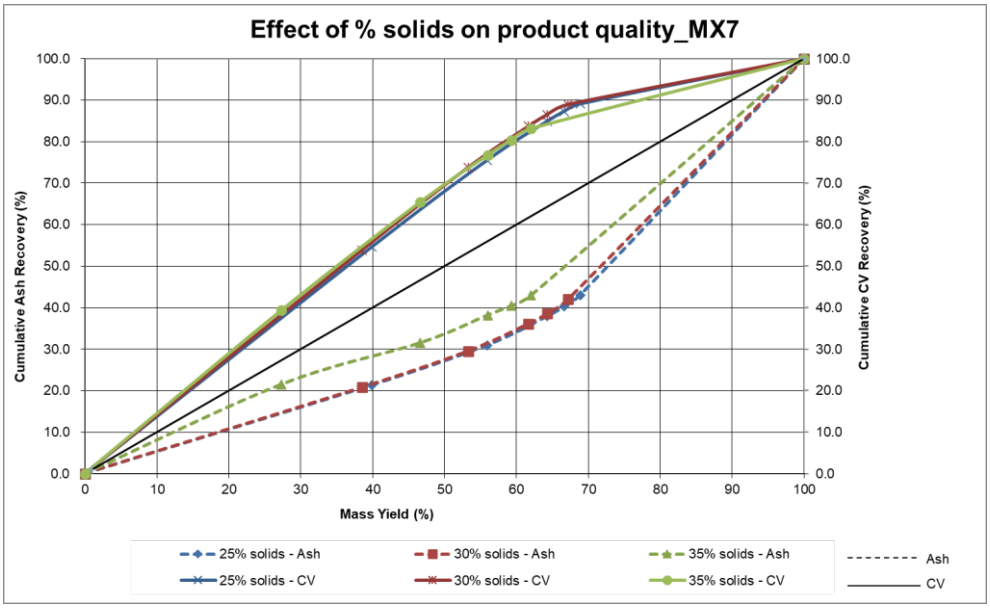

Fig. 5. Effect of % solids (w/w) on product quality on the MX7 spiral

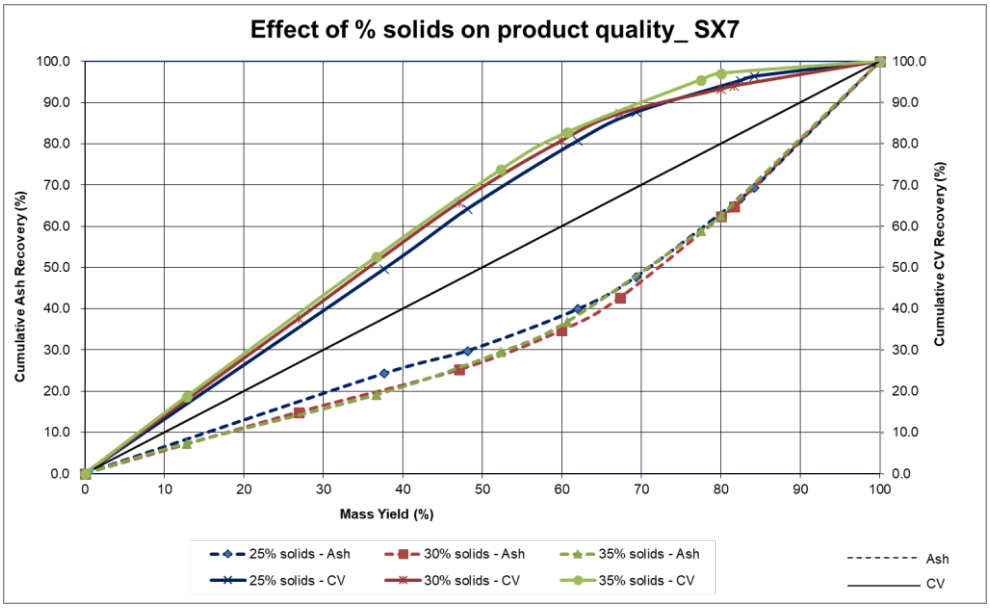

Fig. 6. Effect of % solids (w/w) on product quality on the SX7 spiral

The SX4 spiral, as shown in Fig. *7*, performs best under 25% solids concentration. This condition yields the highest separation efficiency, making it the most favourable for producing a good quality product. It also achieves the highest ash rejection and calorific value (CV) recovery. This performance is consistent with the SX4's design—it is a shorter version of the SX7 spiral. Unlike the SX7, the SX4 does not include an intermediate discard removal point. Therefore, it does not require operation at higher feed solids (e.g., 30%) since no dilution would occur to lower the solids concentration below 25% which is too dilute for a spiral concentrator.

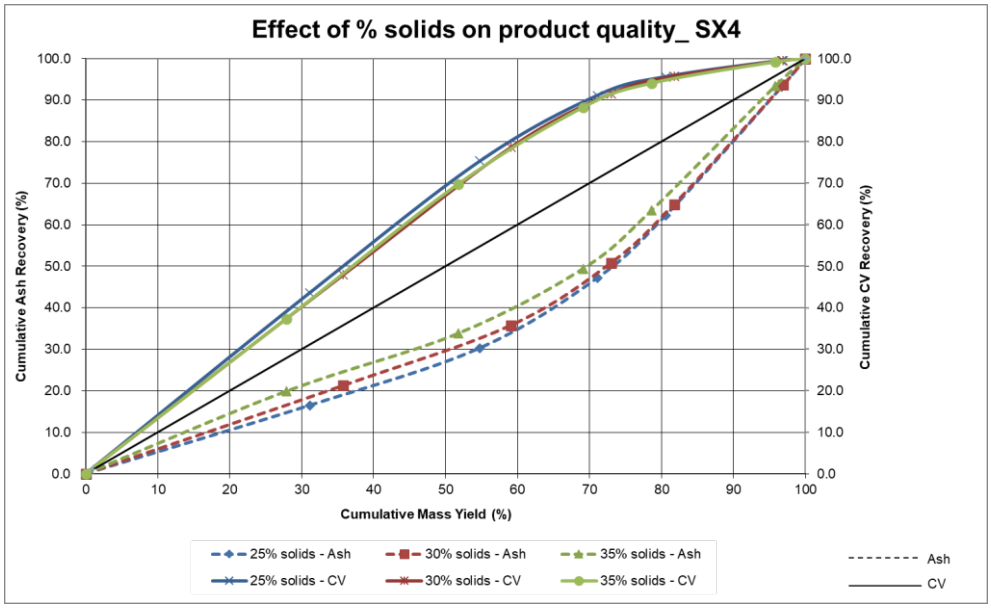

Fig. 7. Effect of % solids (w/w) on product quality on the SX4 spiral

For the SX10 spiral, 35% and 40% solids concentrations give the best results in terms of separation efficiency because of the lowest ash recovery and highest CV recovery. However, the 40% solids operating conditions provides for slightly better results, but again the difference is minimal. The 40% solids concentration is mostly favourable considering that this spiral is the longest version of the SX range of spirals with 10 turns, specifically developed for low density cut point below SG 1.60. A higher solids concentration is favourable for the SX10 because of the two intermediate discard removal points, ensuring that the material still has enough fluidity in last few turns to achieve optimum separation.

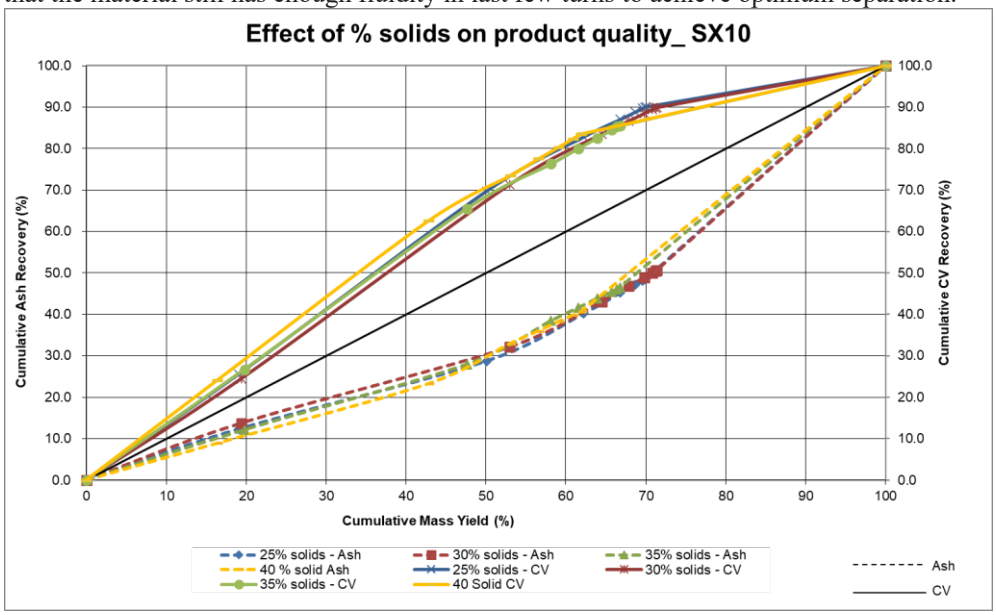

Fig. 8. Effect of % solids (w/w) on product quality on the SX10 spiral

4.3 Phase IB: Effect of throughput on product quality

The graph in Fig. ***9*** illustrates the effect of varying throughput rates (2.0 tph, 2.6 tph, 2.8 tph, and 3.2 tph) on cumulative ash and CV recovery. Contrary to expectations, the throughput at 3.2 tph gave rise to the highest CV recovery and lowest ash recovery on the MX7 spiral implying that the best quality product is achieved at this throughput. The throughput at 2.8 tph is the best alternatives given the fact that 3.2 tph is the maximum prescribed solids rate for the spirals tested.

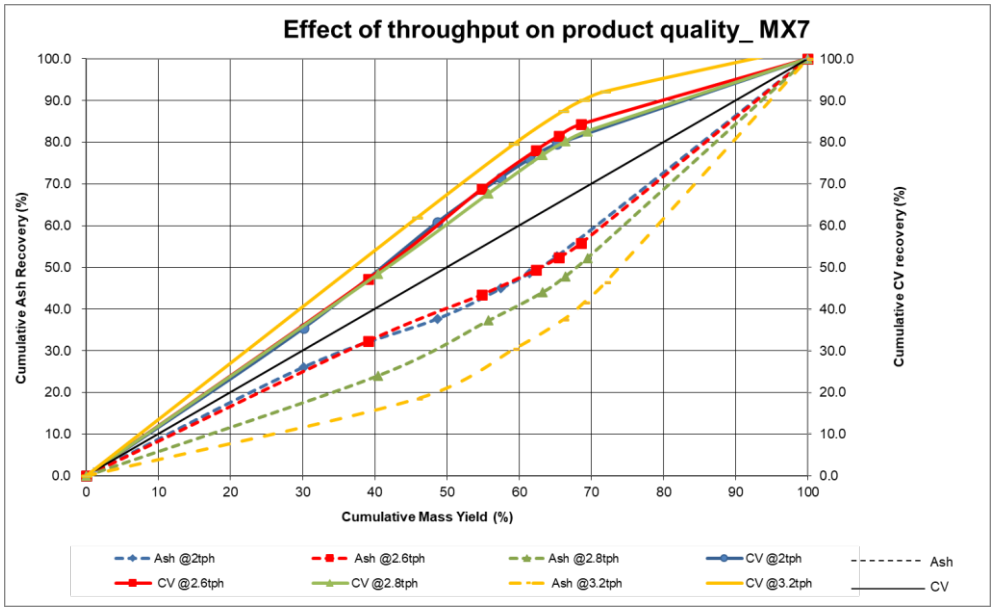

Fig. 9. Effect of throughput (tph) on product quality for the MX7 spiral

In Fig. ***10***, it can be seen that although the 3.2 tph throughput produces the highest CV recovery on the SX7 spiral, it also produces the highest ash making it less desirable for producing a clean coal product. The throughput range at 2.6 -2.8 tph is the optimal range because of the of the balanced effect of CV recovery and ash rejection, ensuring that a high-quality product is produced.

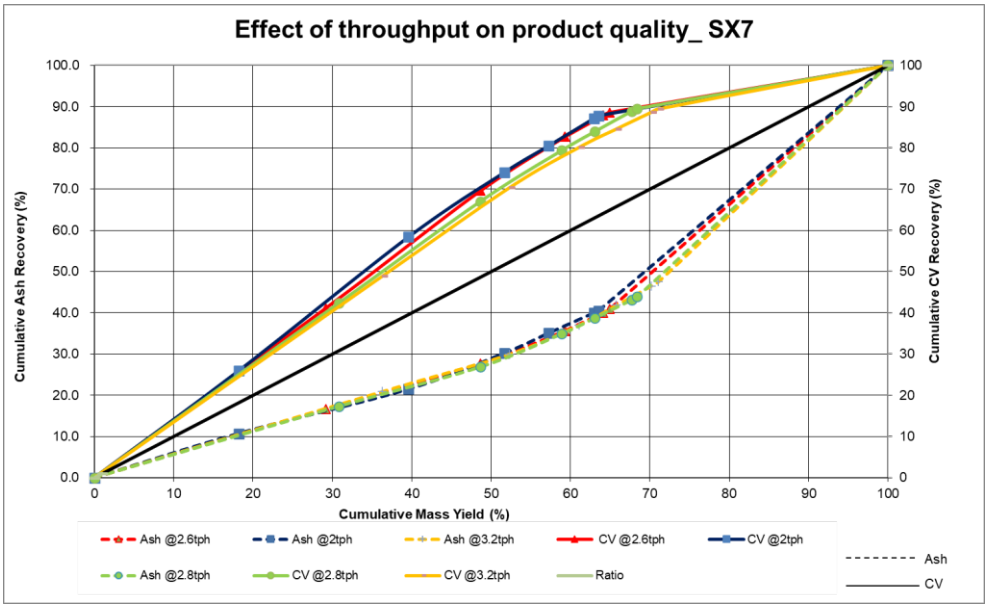

Fig. 10. Effect of throughput (tph) on product quality for the SX7 spiral

Fig. ***11*** shows the variation of throughput rates (2 tph, 2.6 tph, 2.8 tph, and 3.2 tph) on cumulative ash and CV recovery as a function of mass yield for the SX4 spiral. Lower throughputs of 2 tph and 2.6 tph achieve better impurity rejection resulting in a better quality product but at the cost of slightly lower CV being retained.

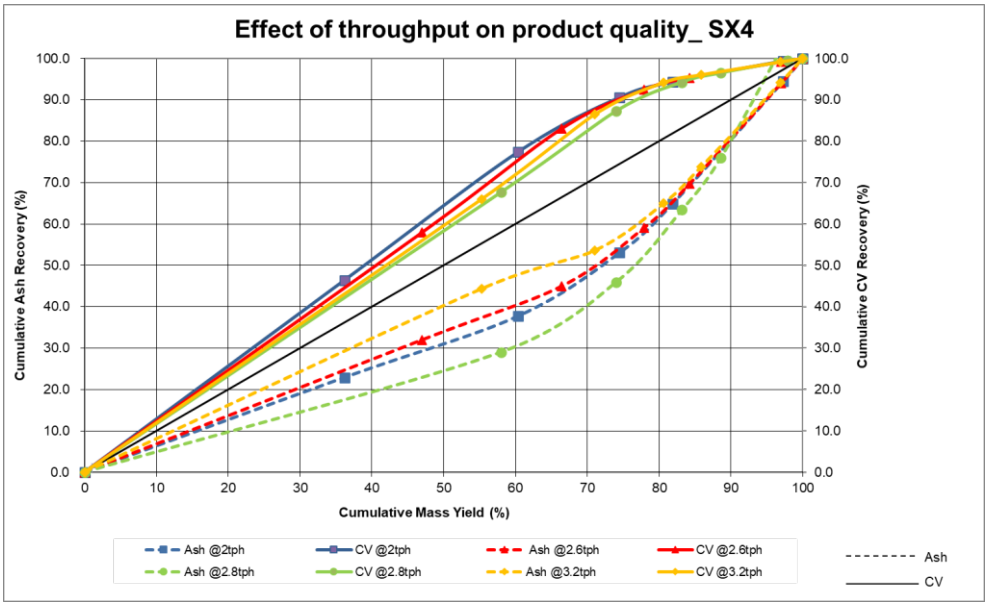

Fig. 11. Effect of throughput (tph) on product quality for the SX4 spiral

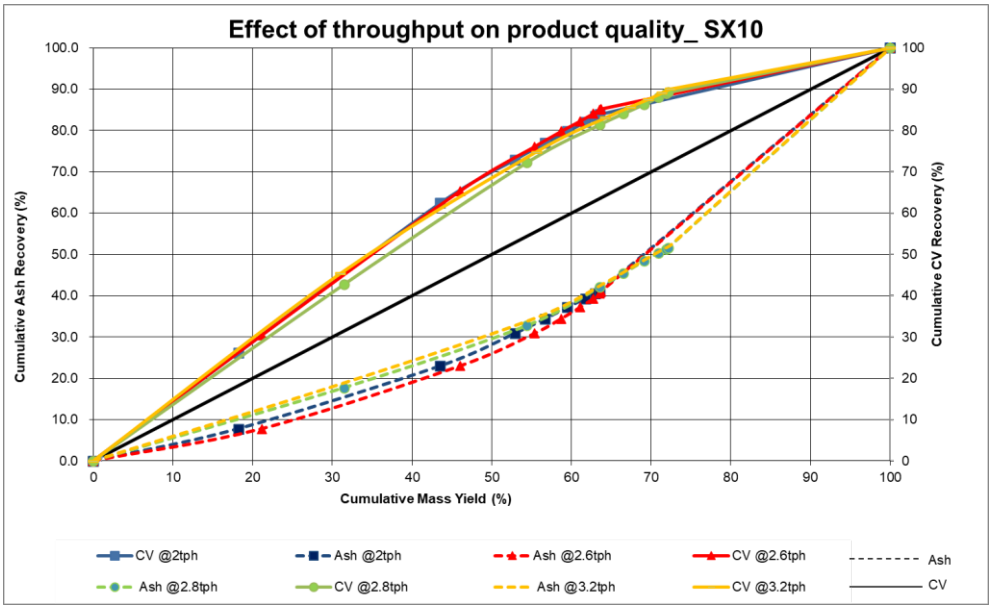

Fig. 12. Effect of throughput (tph) on product quality for the SX10 spiral

As observed in Fig. ***12*** a throughput of 2.6 tph recovers most of the CV while maintaining a product with minimal ash content, thus 2.6tph is the recommended throughput for ensuring that a clean product is achieved with the most CV being retained in the product.

5 Conclusion

The study investigated the effects of % solids concentration and throughput on product quality across different spiral models (SX4, SX7, MX and SX10). The findings indicated that optimal conditions in solids concentration vary across all 4 spirals studied. This finding aligns with our expectation since the design of each spiral is slightly different from each other, and therefore a suitable spiral for a particular application will depend on the operational requirements of the process. In particular, the 30 – 35% solids concentration range was found to be ideal for the MX7 and SX7 spirals with 30% being the optimal concentration. A 25% solids concentration was found to be optimal for the SX4 spiral yielding a product with the lowest ash while retaining most of the CV in the product. The SX10 spiral demonstrated optimum performance when operated at 40% solids yielding a product with the lowest ash while also retaining much of the CV in the product.

Similarly, the effect of throughput on product quality also varied across all 4 spirals. At 3.2 tph solids throughput, the MX7 demonstrated its highest ash rejection capacity while recovering most of the CV to the product compared to other throughputs. This is, however, contrary to the expectations, because 3.2 tph is the maximum prescribed solids throughput recommended on Multotec coal spirals. This highlights the need to take a precautionary measure to limit the throughput to 2.8 tph as a conservative optimal throughput approach, subject to confirmation through other investigations. In the case of the SX7 spiral, a throughput of 2.6 tph was found to be ideal for low % ash being recovered to the product. A throughput of 2 - 2.6 tph is the best option for the SX7 if CV is prioritised over impurity control. The SX10 produced the best performance when operated at 2.6 tph striking a good balance between ash and CV recoverable.

While this work does not specifically target fixed ash values or associated mass yields, it supports the use of separation efficiency profiles as a practical means to infer optimal operating conditions, avoiding the constraints of fixed product ash or yield specifications.

There were, however, some limitations that existed during the study. Usually, on a study such as this, testwork should be conducted in triplicate to confirm and to ensure reproducibility of results obtained. However, due to sample limitations and the magnitude of the scope of work, the study was limited to a single run per test which prompted for extra caution to be undertaken to ensure that the integrity of each test is preserved. This was achieved by ensuring that density control is always maintained during testwork by following a set of strict guidelines, while also ensuring that sample management, including blending, splitting, and sub-sampling follows Multotec prescribed set of standards. Testwork was, however, repeated on cases where outliers were greatly pronounced.

The future prospect of the current study is significant, for phase II of the research, focus will be on the washability studies to evaluate the separation efficiency across all 4 Multotec coal spirals. Phase II will be conducted under optimised operating conditions investigated here, to ensure accurate assessment of spiral performance in terms of equipment - characteristic - parameters, E_p and d_{50}, which are unique for each spiral model. This will ensure that correct equipment selection is achieved to suit specific process. Obtaining these parameters will also reduce operational uncertainty by ensuring the right equipment is selected with absolute guarantee the best possible product quality will be achievable to meet the required downstream process outcomes.

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