Evaluating separation efficiencies of Multotec's new SC25 spiral on coarse chromite

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ABSTRACT

Spiral concentrators are widely applied to beneficiate commodities such as Cr_2O_3, mineral sands, and ferrochrome. The application of spirals for heavy minerals has been limited to a feed top size of 1 mm. At particle sizes larger than this, friction retards heavy particles and the particles' primary velocity approaches zero, resulting in a solids build-up, therefore inhibiting further separation. Recently, a new Multotec SC25 spiral model was introduced to the industry, which aids in beneficiating particles of up to 3 mm, with successes having been demonstrated in ferrochrome slag and titanium-bearing minerals. This spiral also has potential in electronic waste applications.

This paper examines the applicability of the SC25 spiral in coarse Cr_2O_3 recovery. This stems from the fact that junior chrome miners tend to discard particles larger than 1 mm as they neither have milling nor dense media circuits. Also, alluvial chrome miners discard +1 mm even though this size fraction contains recoverable and liberated Cr_2O_3.

The SC25 spiral has shown better Cr_2O_3 separation efficiencies than the SC21 model and with higher SiO_2 rejection at saleable grades, thus providing an additional revenue stream specifically for the coarser (+820 µm) size fractions.

Keywords: spiral concentrators, chromite recovery, specific gravity, SC25 spiral, coarse spiral

1. Introduction

1.1. Spiral concentrators

Spiral concentrators beneficiate minerals with significant differences in specific gravity (SG). Separation is achieved by a combination of actions that include stratification, film sizing, centrifugal and gravitational forces that are experienced by the particles as the slurry flows down the helical structure (Diketane *et al*., 2019). As the slurry flows down, centrifugal forces cause the water and lighter particles to report to the outer area. The velocity of the slurry stream decreases with depth (due to friction from the spiral surface), the bottom layers are retarded, and heavy minerals move inwards towards the center (Davies *et al*., 1991). Holland-Batt (1992, 1995, 2009) and Holland-Batt and Holtham (1991) described the phenomena of primary and secondary flow on the spiral surface. The primary flow is responsible for the downward transport of particles. The secondary flow is the radial flow in the upper and lower layers of the fluid.

1.2. Factors affecting separation on spirals

Feed properties such as particle size, particle shape, feed density, and medium viscosity contribute to the effectiveness of separation on a spiral. The effectiveness of separation is also dependent on spiral geometry. Atasoy and Spottiswood (1995), identified trough profile, diameter, and pitch as the main spiral geometry factors affecting mineral separation. Heavy mineral spirals tend to have a higher pitch (and higher descend angle) than those for less dense minerals like coal. Coal spirals that are currently in the market can handle material with a top size of 3 mm, whereas applications for heavy minerals have been limited to a top size of 1 mm (Diketane *et al*, 2019).

1.3. The behaviour of heavy, coarse particles in spirals

Diketane *et al* (2019) mentioned that when heavy minerals with top size in the range 1 to 3 mm flow down the spiral, its velocity is retarded and its primary velocity approaches zero. As a result, solids build-up (beaching) takes place, thus inhibiting further separation down the spiral. These large and heavy particles tend to slide from the fluidized region of the spiral into the inner, less fluidized portion. This creates difficulties in keeping the heavy, large particles (in excess of 1 mm) in motion (Diketane *et al*, 2019).

1.4. SC25 spiral model

This is a new spiral developed by Multotec to process heavy, coarse minerals. The traditionally utilized SC21 and the newly developed SC25 spiral models are almost identical. The main difference is that the SC25 is a much steeper spiral than the SC21 model. Diketane *et al*, (2019), compared the SC25 with other spiral models traditionally used in heavy minerals applications. The models that were compared are however designed to process feed material with a top size of 1 mm. Comparisons on a kimberlite-bearing ilmenite ore showed that the SC25 spiral achieved 20 % more ilmenite recovery than the HX5 spiral at similar product grade with feed top size of 3 mm. Further tests by Diketane *et al* (2019) on ferrochrome slag showed that the SC25 achieved almost double the separation efficiency than the SC21 spiral at a rougher stage with a feed top size of 3 mm. Diketane *et al* (2019) also tested the effect of high SG materials by comparing the two spirals (SC25 and SC21) on feed to the re-cleaner stage on ferrochrome with a top size of 1 mm. The SC25 also proved superior in terms of metal recovery and separation efficiency. This led to the question: where else can the SC25 spiral be applied?

1.5. Urban mining-specifically electronic waste recycling

Electronic waste recycling has been gaining momentum in recent years. Electronic circuit boards contain metals that can be recovered if the boards are crushed, so that the metal has a top size in the range of 1 mm to 3 mm. There are distinct SG differences between the metal and plastics such that the metal can easily be recovered by means of gravity concentrators such as spirals and shaking tables. The high SG and the top size of the metal can result in a decrease in efficiency on traditional fine spirals. The capacity limitations on shaking tables, and with the ever-growing demand for urban mining, there has been a growing need for a unique spiral geometry that will provide optimum separating conditions for this industry. The SC25 spiral has the potential to cover this gap.

1.6. Chrome recovery application

Artisanal and junior miners generally have limited resources such that they opt for low-cost mining and processing methods. Countries such as Zimbabwe have alluvial, liberated Cr_2O_3 deposits that lie at the surface within the valleys. The chrome-bearing ore is hauled to the plant, scrubbed and screened before feeding the minus 1 mm fraction into spirals. The plus 1 mm size fraction is then discarded even though it contains liberated and recoverable Cr_2O_3.

The MG (Middle Group) and LG (Lower Group) chromite seams in South Africa are generally exploited for use of its metallurgical grade Cr_2O_3 content in the ferrochrome industry. Some junior chrome miners of these seams, tend to discard particles larger than 1 mm as it neither has milling nor dense media circuit capabilities. When using spirals, the Cr_2O_3 concentrate recovery from these seams have certain challenges, even for the minus 1 mm fraction. The rejection of coarse SiO_2 for these ores is problematic on traditional spirals, thereby reducing separation efficiencies.

This paper assesses the efficiency of Multotec’s newly developed SC25 spiral when treating a Cr_2O_3 ore with a top size of 3 mm application. Comparisons are made to the SC21 spiral for size fractions below 1 mm as well as to assess other potential avenues for its applications.

2. Experimental

2.1. Test-work conditions

LG6 samples from the Bushveld Igneous Complex (BIC) in South Africa were acquired with a size range of up to 3 mm. The bulk sample was blended and screened to produce three size range samples (-3000 µm, -3000 µm +820 µm and -820 µm). The SG of each sample was determined and particle size distribution (PSD) determined. Table 1 shows the size ranges and sample SGs.

Table 1

The three size range samples prepared for the test

Size range	Sample SG	Description
-3000 µm +0 µm	4.14	Full-size range
-3000 µm +820 µm	4.03	Size range being discarded by the mine
-820 µm +0 µm	4.56	Size range being fed to SC21 spiral plant at the mine

Figure 1 below shows the PSD for the range -3000 µm. This plant operation discards the +820 µm fraction, due to the low Cr_2O_3 grade and high SiO_2 content on this fraction. This equates to approximately 20 % of total feed to plant being thrown away.

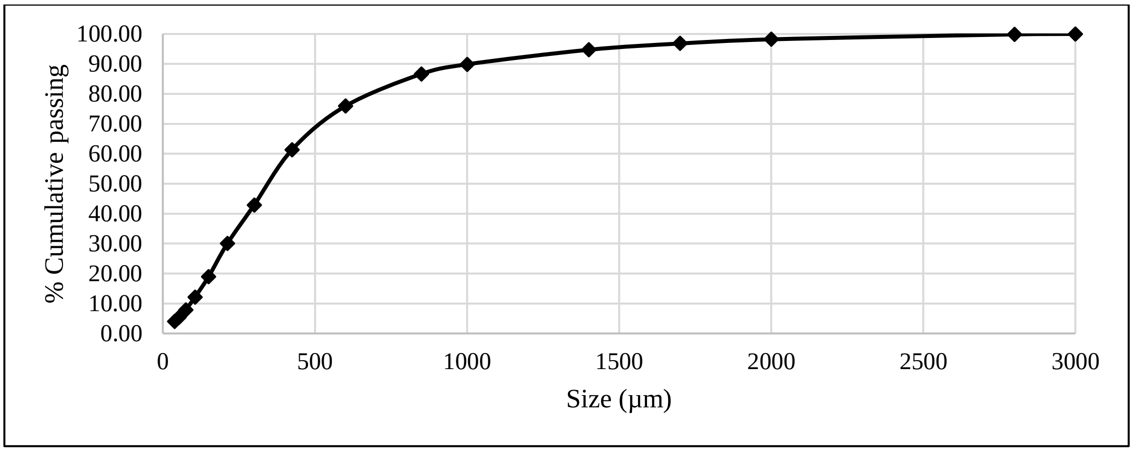

Fig.1. Particle size distribution for the -3000 µm size fraction

The slurry was fed to the spiral via a distributor with an overflow pipe to maintain a constant feed rate into the spiral. This was a closed-circuit spiral test with a sump and pump. During each test, the spiral was run until steady-state conditions were reached before taking the relative density (RD) measurements at the top of the spiral rig. The simultaneous timed samples were taken from the mouth organ product box only once the spiral feed RD and flow rate measurements were found to be consistent. The samples were analysed by an external laboratory by means of XRF methodology.

Table 2 shows the target and achieved test conditions for the different size ranges. The test conditions chosen were based on Multotec's guidance for the SC21 spiral.

Table 2

Spiral test conditions

Size Range	Spiral model	% solids by weight (target)	% solids by weight (actual)	Dry solids (t/h)	Water (t/h)
-3000 µm +0 µm	SC25	30	31.1	1.4	2.9
	SC21	30	31.8	1.4	3.0
-3000 µm +820 µm	SC25	30	32.5	1.4	2.9
	SC21	30	31.8	1.2	2.9
-820 µm + 0 µm	SC25	35	33.3	1.5	3
	SC21	35	37.7	1.7	2.8

2.2. Separation efficiency on a spiral

Yield, grade and recovery are the main separation attributes used to measure the performance of a spiral. This paper uses the mentioned attributes in addition to the Hollard-Batt equation to calculate separation efficiency. The separation efficiency by Hollard-Batt as reported by Fourie (2007) can be seen in Eq. (1):

$$\text{Separation efficiency}=\frac{\%\text{ Recovery - }\%\text{ Yield}}{100\text{ - }\%\text{ Feed grade}}\text{ x }100 \tag{1}$$

For testing purposes, a mouth organ product box was used, with fractions ranging from A to H, instead of the traditional three-product box (concentrate, middlings and tailings). For the mouth organ application, the heavy mineral concentrate is spread out from Fraction A towards H, with the opposite trend being true for the tailings. The purpose of this product box, is that it allows for smoother result curves, with more data on important transition points. An added advantage of using a mouth organ product box during test work, is that the product splitter position is removed as a test variable, enabling like-for-like spiral efficiency comparison.

3. Results and discussion

3.1. Results for the -3000 µm rougher stage

Figure 2 shows the relationship between grade and mass yield for both Cr_2O_3 and SiO_2. The material had a feed grade of approximately 39 % Cr_2O_3 and 12 % SiO_2.

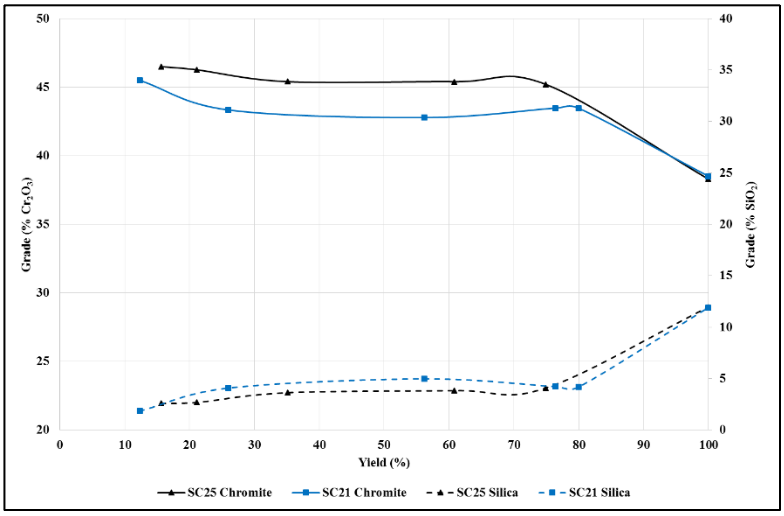

Fig.2. Cumulative grade versus the cumulative yield for -3000 µm

Taking the mass yield at 40 % as a reasonable mass recovery to the concentrate on this type of material, it can clearly be seen that the SC25 achieved a cleaner product that the SC21.

Figure 3 shows the recovery versus the mass yield curve for the SC25 and SC21 spiral models.

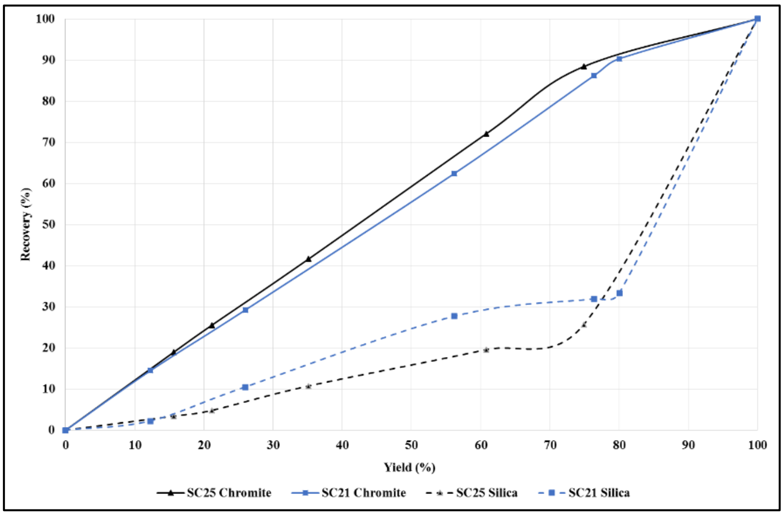

Fig.3. Cumulative recovery versus cumulative mass yield on -3000 µm

Again, at a mass yield of 40 %, the SC25 spiral achieved a higher Cr_2O_3 and lower SiO_2 content into the concentrate.

Figure 4 shows the separation efficiency achieved by each spiral.

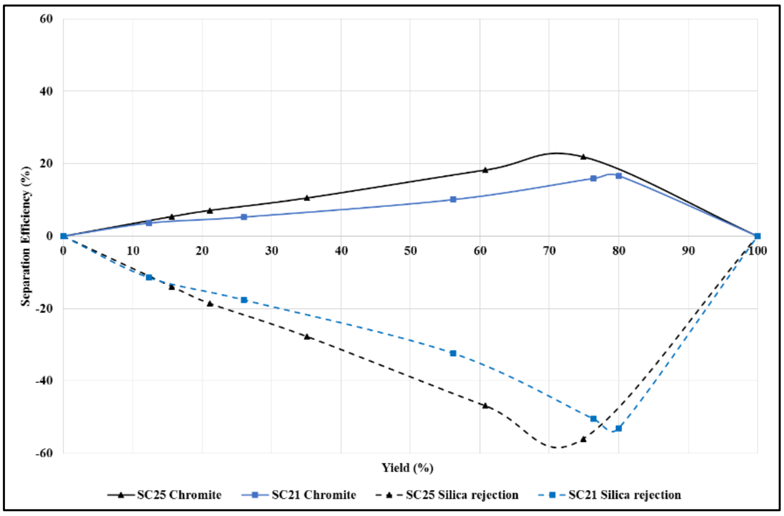

Fig.4. Cumulative separation efficiency versus cumulative mass yield for -3000 µm

At a mass yield of 40 %, the SC25 achieved a higher separation efficiency in terms of Cr_2O_3 as well as in terms of SiO_2 rejection. This can also be seen throughout the yield range.

3.2. Results for the -3000 µm +820 µm rougher stage

Figure 5 shows the relationship between grade and mass yield for both Cr_2O_3 and SiO_2. The material had a feed grade of approximately 23 % Cr_2O_3 and 30 % SiO_2. This coarse material had a low grade and high SiO_2 content, which is a contributing factor to the discarding of this size range for this particular plant operation.

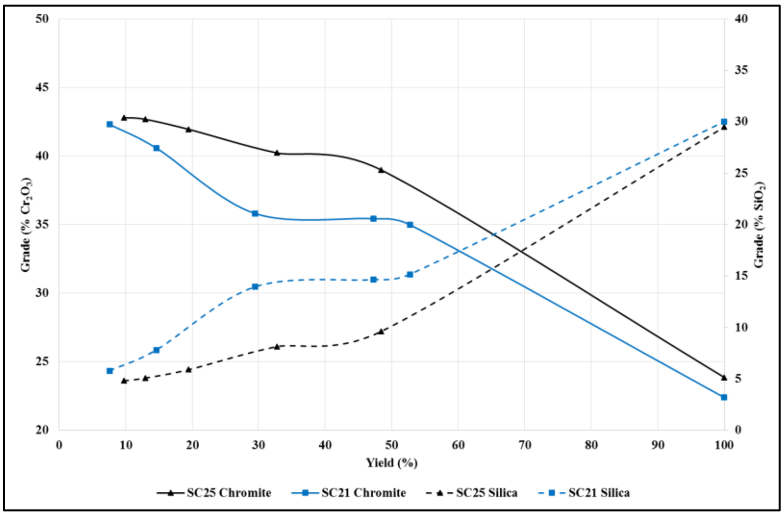

Fig.5. Cumulative grade versus cumulative mass yield for +820 µm -3000 µm

Taking 40 % mass yield as a reasonable mass recovery to the concentrate for this type of material, it can be seen that the SC25 achieved a cleaner product than the SC21, as was the case with the -3000 µm range.

Figure 6 below shows the recovery versus mass yield curve, where at a 40 % mass yield, the SC25 spiral achieved a higher Cr_2O_3 and lower SiO_2 recovery into the concentrate than the SC21.

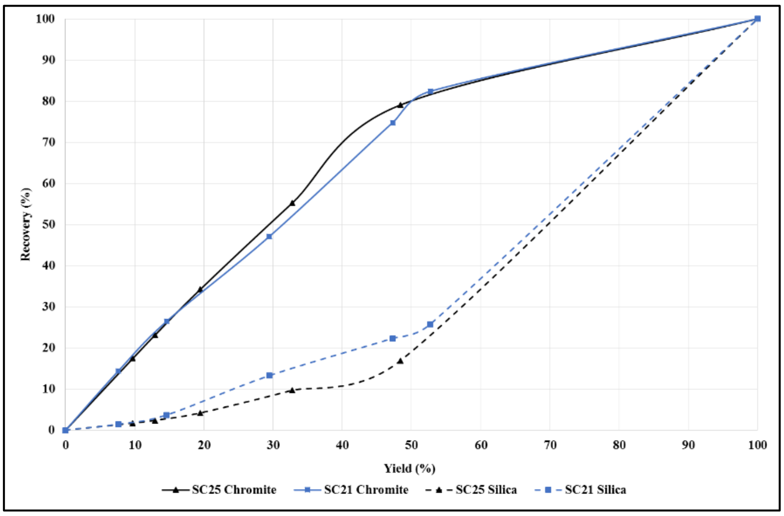

Fig.6. Cumulative recovery versus cumulative mass yield for +820 µm -3000 µm

Figure 7 shows the relationship between the cumulative separation efficiency and cumulative mass yield.

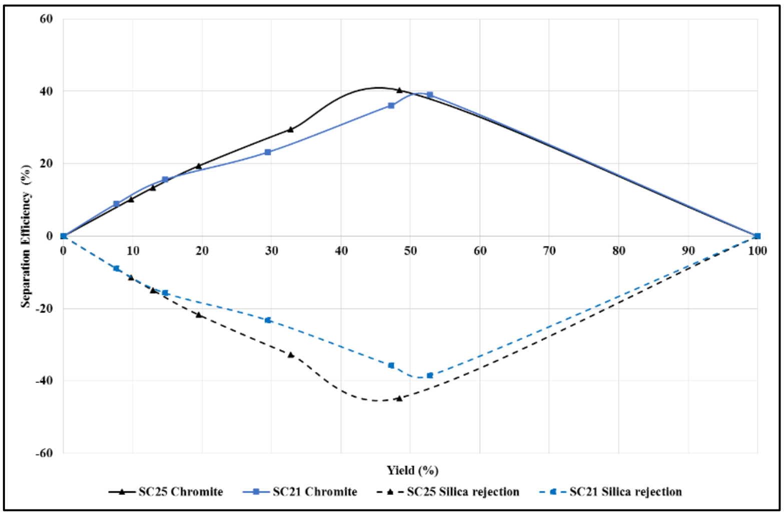

Fig.7. Cumulative separation efficiency versus cumulative mass yield for +820 µm -3000 µm

The SC25 Cr_2O_3 curve lies above the SC21 up to the required mass yield. Also, the SC25 shows a high efficiency in terms of SiO_2 rejection. Observations during testwork also showed that the SC25 does not beach for this size material and this might be an explanation for the better separation efficiency on the SC25 spiral model.

Given that this is the material that the plant currently throws away, the SC25 shows that a saleable product can be produced on this size range. Considering total feed to plant at 100 tph and that 20 % of the material is discarded based on PSD, then it is possible to recover 40 % of the discarded material. At $140/ton selling price of chrome and 85 % plant availability a month, this equates to approximately $700 000/month in lost revenue.

3.3. Results for the -820 µm rougher stage

Figure 8 shows the relationship between cumulative grade and cumulative yield for both spirals.

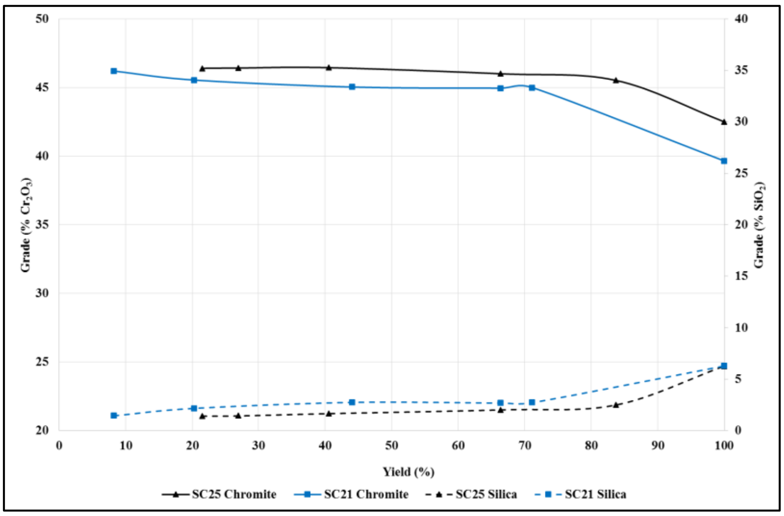

Fig.8. Cumulative grade versus the cumulative yield for -820 µm

At a yield of 40 %, the SC25 shows a slightly higher Cr_2O_3 grade and slightly lower SiO_2 than the SC21. This is not only observed at 40 % yield, but throughout the whole yield range. However, the SC21 achieves better recovery than the SC25 as shown in Figure 9. This shows that the SC25 could have a role to play in a spiral circuit where product purity is more important than recovery.

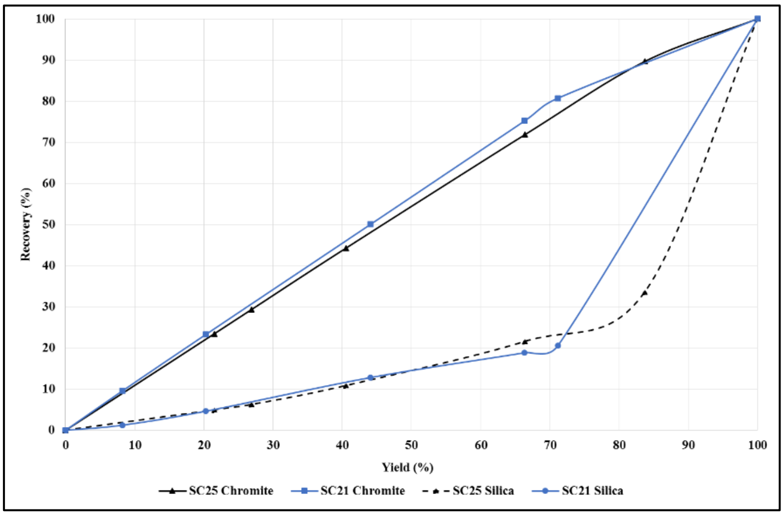

Fig.9. Cumulative recovery versus cumulative mass yield on -820 µm

Figure 10 shows the relationship between the cumulative separation efficiency and cumulative yield for SC25 and SC21 spiral.

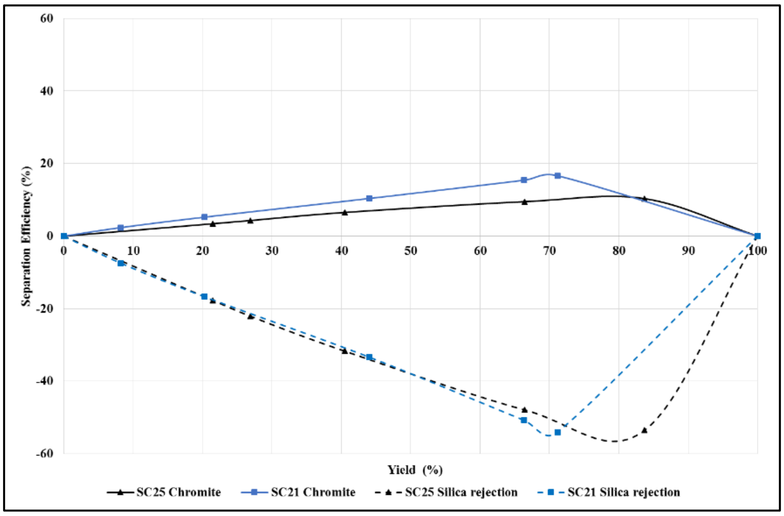

Fig.10. Cumulative separation efficiency versus cumulative mass yield for -820 µm

The SC21 achieved a better Cr_2O_3 separation efficiency at 40 % mass yield and throughout the mass yield range. However, in terms of SiO_2 rejection, both spirals achieved similar efficiencies. The SC21 spiral was designed for -1 mm size fraction and it is no surprise that overall, it achieves better efficiencies on the size range below 820 µm.

4. Conclusions and Remarks

The main aim of the work was to investigate the applicability of the newly developed SC25 spiral in Cr_2O_3 recovery. The spiral was developed for coarse heavy minerals and was successfully demonstrated with ferrochrome slags. Different size fractions were tested in the range up to 3 mm. The SC21 spiral, which is applicable for the minus 1 mm size range, was used as a benchmark.

The SC21 spiral showed better Cr_2O_3 separation efficiencies and higher recoveries than the SC25 in the minus 820 µm size range. This is expected, and corresponds with the size range with which the SC21 is applicable. However, in terms of SiO_2 rejection efficiency, both the SC21 and SC25 showed similar separation efficiencies at this size range.

The SC25 spiral achieved better separation efficiencies and higher recoveries than the SC21 in the size ranges, -3000 µm +0 µm and -3000 µm +820 µm. Given that the mine that provided the sample was discarding the +820 µm size fraction, then based on the PSD and Cr_2O_3 grade and recovery curves, the SC25 has the potential to add revenue of approximately $ 700 000/month based on February 2020 figures. It will also provide alluvial chrome miners with an additional revenue source on the size fraction that is generally discarded. This work has shown that the SC25 is not only a process optimization game changer in metal recovery from ferrochrome slag but it has the potential to be applied in the niche market of coarse chrome recovery and with huge potential in electronic waste recycling.

An added advantage of using the SC25 is that, where traditionally beaching is encountered when passing coarse material over the SC21, the material flows without hindrance on the SC25 in a coarse chrome application.

Thus, the SC21 has its place in the heavy mineral circuit (minus 1 mm size range), while the SC25 has its place in the circuit, specifically at coarser fractions.

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