Recovery of ultra-fine chrome with spiral concentrators - where are we?

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Spiral gravity concentrators have undergone extensive development in recent years, with a greater emphasis on ultrafine particle recovery. The different ore bodies and differences in the initial processing stages prior to feeding the spirals present their own challenges in the design features of these ultrafine spirals aimed at improving recovery efficiency of -53 µm fractions. MetQ's two ultrafine spiral models (M10A and M10B) are discussed. The M10A model was created for a narrower particle size range and the M10B spiral was created for a wider size range. How the recovery of ultra-fine chromite impacts the grade of the platinum group metals (PGMs) is studied, offering new thoughts on gravity concentrators in plant design considerations for PGMs and chromite recovery plants. The M10A model utilises the variance of the particle's specific gravity within the same size range (<53µm) to maximise the recovery of chromite (Cr_2O_3). With a feed grade of 19.89% Cr_2O_3 and 29.38% SiO_2 after a rougher stage 46.93% of chromite and 29.66% SiO_2 by mass was recovered to the concentrate with grade of 27.0% Cr_2O_3 and 21.8% SiO_2. A tail with a grade of 12.92% Cr_2O_3 with a 17.88% mass yield was achieved. The M10B is effective at upgrading material with a low feed PGM grade. After a single stage it increased the PGMs from 0.64 g/t to 1.02g/t. The spiral uses its unique profile to increase its chromite separation efficiency. Feeding the spiral with a grade of 19.89% Cr_2O_3, a 35% chromite recovery by mass was achieved with a tail grade of 11.48% Cr_2O_3. Both the M10A and M10B spiral capabilities maximise overall plant chrome recovery by recovering chromite that would otherwise be lost when using a traditional spiral, while also improving the PGM grade in the spiral tails.

LITERATURE REVIEW

The spiral concentrator is essentially an inclined trough with a complex cross-section wrapped around a central column. Spirals are ideal in large operations for their low energy consumption. The separation of particles is influenced by the gradient and surface area of the trough. Gravitational force, centrifugal force, hydrodynamic drag, and Bagnold force are the main forces known to act on particles in a spiral (Izerdem & Ergun, 2018). A spiral concentrator product box usually has three outlets namely concentrate, middling, and tail.

The optimum particle size required for feeding on a spiral is between 75 µm-3 mm (FALCONER, 2003). Conventionally spiral concentrators treating finer material had to contend with lower separation efficiencies, grades, and recoveries when compared to those treating coarser material (HENDERSON & MacHUNTER, n.d.). Spiral concentrators are inefficient at recovering very fine-sized material (<53 µm), which reduces overall separation (Goodman, et al., 1985). Ultrafine particles (<53 µm) tend to report to the tailings on a traditional spiral. This is due to the force associated with water flow taking precedence over gravity as the particle size decreases (Murthy, et al., 2011).

In South Africa, PGMs are concentrated in the Bushveld igneous rock, which has three main reefs: Merensky, UG2, and Platreef. UG2 and Platreef are currently the primary source of PGM production (Corin, et al., 2021). Due to the complex minerology of UG2 and Platreef it is difficult to beneficiate them compared to Merensky. The UG2 Reef is primarily made up of chromite (60–90%), gangue silicates, orthopyroxene (5–25%), plagioclase (5–15%), and base-metal sulphides (BMS) (1%) (Beer, 1996). UG2 and Platreef reefs have a high proportion of ultra-fine PGMs (<10 µm) (Corin, et al., 2021). Improved beneficiation circuits have been implemented to target PGMs without overgrinding, namely Mill-float (MF1), Mill-Mill-Float (M2F), Mill-Float-Mill-Float (MF2) and Mill-Float-Mill-Float-Mill-Float (MF3) (Beer, 1996). MF2 circuits are commonly used in the PGM industry. The coarse BMS and fine platinum sulphide minerals are separated in different circuits in this stage-by-stage collection of concentrate (Corin, et al., 2021).

Fine grinding of ore result in high recovery of chromite in the PGM concentrate via entrainment (Corin, et al., 2021). To avoid this from occurring most operations use gravity separators to pre-treat and recover the chromite before sending the material to flotation. Gravity techniques are well established and widely accepted for concentrating chromite ore, but they become inefficient and complex when dealing with fine particles (less than 75 µm) (Murthy, et al., 2011). In a case where traditional spirals are used as gravity concentrators the middling and tails will be sent for secondary grinding. These streams till contain large amounts of ultra-fine chromite which was not recovered, resulting in high chromite problems in the PGM concentrate. Chromite is a spinel mineral that forms stable species up to 2000°C, and these stable species can have a significant impact on smelting efficiency (O'Connor & Alexandrova, 2021).

The increase in demand for chromite has given rise to chromite producers investing in economic and efficient downstream strategies to capture ultra-fine chromite which was historically regarded as tails. The MetQ spiral prototypes (M10A and M10B) are utilised in such operations. These prototypes are popular on both the eastern and western limbs of the bushveld. M10A has around ten installations in South Africa. It is largely preferred by small operations, while the M10B has one installation. These new spiral models are set apart by the design of the pitch , profile and helix length. The vertical distance between similar points on successive helix turns is known as pitch. A profile is made up of an inner area for transporting separated heavy minerals and a flatter, larger section where heavy minerals are constantly separated. The M10A has a steeper pitch compared to M10B. A preferred pitch for a specific feed should ideally ensure particle fluidity (DAVIES, et al., 1991).

Materials and Methods

The tests were conducted with UG2 material, previously processed through a MF2 plant, followed by an eight stage spiral plant. The material was then dewatered with a cyclone, and the cyclone's underflow served as the spiral test material feed. Only the rougher stage was used to compare the two spirals (M10A and M10B). The tails of this test would serve as feed to an MF1 circuit. The spirals were fed at a density of 1.35 t/m^3 in a closed circuit. The distributor's aperture was used to manage the tonnages on each spiral. M10A utilised a 20 mm orifice and M10B utilised a 25 mm orifice. Figure 1 shows the flow chart. The spirals were given enough time to allow a steady state flow before positioning the cutters on each spiral.

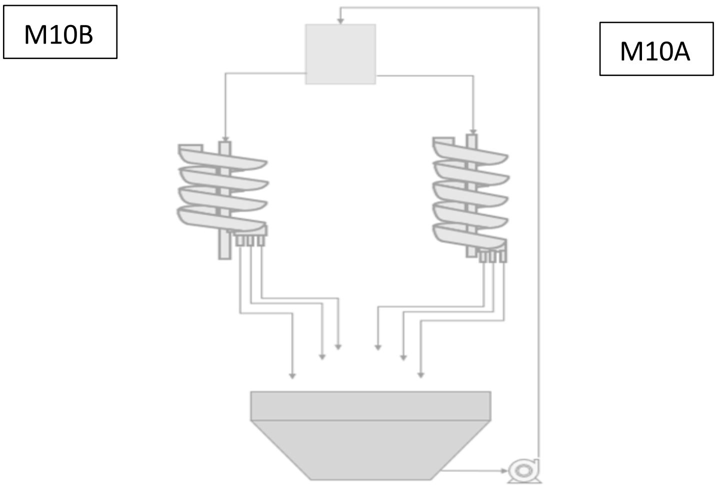

Figure 1. MetQ spiral test plant, process flow diagram.

The UG2 material fed had a chromite content of 19.80%, a silica content of 29.38%, and a PGM(4E) content of 0.64 g/t. The material's bulk density was 3.8 t/m³. Individually, the traditional spiral M50 was tested with the same material. The M50 spiral model has traditionally been used in most operations to recover fine chromite where the feed has lots of ultra-fine particles after it has gone through MF2 circuit.

Table I. Spiral model specifications

Spiral Parameters			
Spiral Model	**M10A**	**M10B**	**M50**
Spiral Diameter (mm)	710	1000	1000
Solid%(w/w)	30-40	30-40	35-45
Ton/helix	0.8-1.5	1-3.5	2-4.5
Number of Turns	4	5	5

Figures 2 and 3 show the cross-section of the M10A and M10B spiral. The M10A profile is built in a bowl shape and the M10B has a flat profile.

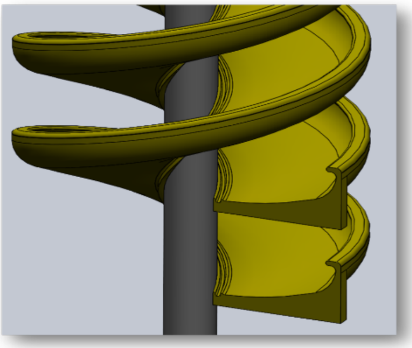

Figure 2. Illustration of M10A profile, steeper pitch.

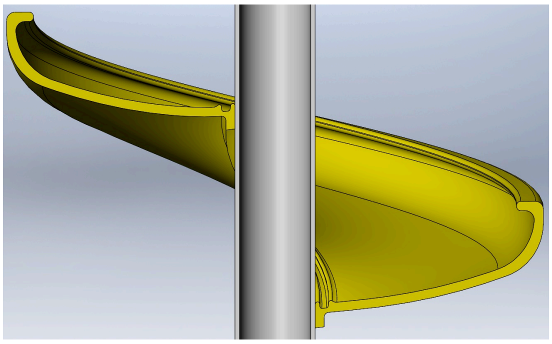

Figure 3. Illustration of M10B profile gentle pitch.

RESULTS AND DISCUSSION

Feed to each spiral was tested three times, all running at the required tonnages and solids percent (w/w) according to the spiral specifications. Overall tonnages and solids percent (w/w) are shown in Table II.

Table II. Test-work parameters

Run	M10A		M10B		M50	
	Solids%(w/w)	**Ton/hr**	**Solids%(w/w)**	**Ton/hr**	**Solids%(w/w)**	**Ton/hr**
1	34.42	0.85	34.42	1.66	36.2	3.9
2	33.55	0.96	33.55	1.68	35.1	4.3
3	34.5	0.88	34.5	1.7	37.2	4.1
Average	**34.16**	**0.90**	**34.16**	**1.68**	**36.17**	**4.10**

Figure 4 shows that M10B has the highest chromite content when compared to M10A and M50 at both low and high mass yields. Looking at M10A and M10B, they are both efficient at upgrading from a rougher stage, which usually targets high mass yield.

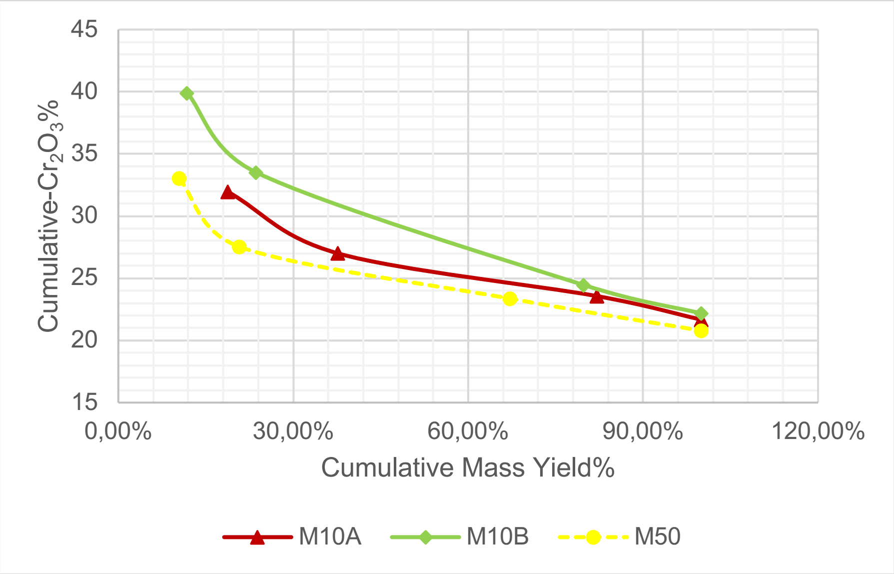

Figure 2. Cumulative chrome grade vs cumulative mass yield%.

Traditional spiral concentrators used to treat finer material had lower separation efficiencies, grades, and recoveries. The M10A tail had a chromite content of 12.92%, the M10B tail had a content of 11.48%, and the M50 tail had a content of 14.50%. When compared to M10A and M10B spirals, the M50 spiral recovers more chromite to the tailings. This demonstrates how ineffective the traditional spiral is at recovering particles smaller than 53 µm.

The high chromite content of the M50 tailing as shown in Figure 5 will reduce the PGM feed quality of the flotation plant. This will result in high chromite recoveries due to entrainment during flotation, lowering the quality of PGM concentrate and affecting downstream processes.

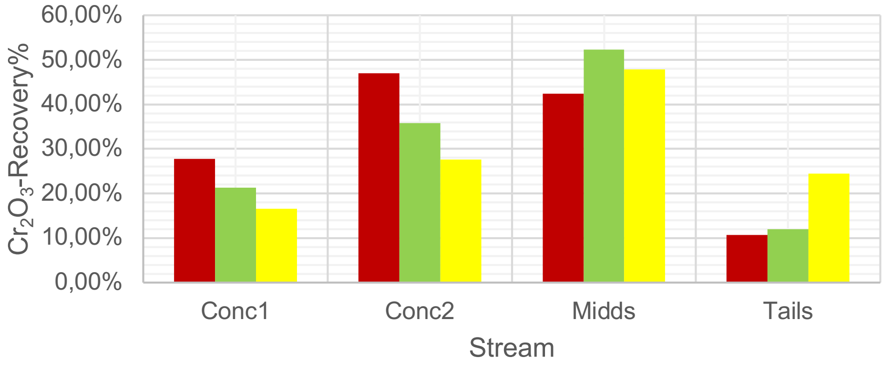

Figure 5. Chromite recovery on each stream.

Figures 6 and 7 depict the feed and tails of M10A and M10B. The M50 was ignored due to the high chromite content of the tailing. Figure 4 shows that high recoveries of ultrafine chromite to concentrate significantly improve the PGM grade. The PGM grade before the material passed through the spirals was 0.64 g/t. After recovering the chromite, the M10A spiral tails PGM grade was 0.95 g/t and the M10B spiral tails are 1.02 g/t PGMs.

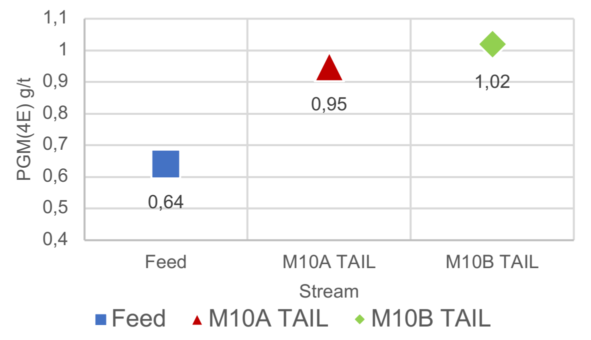

Figure 6. PGM content in the feed and tails produced by M10A and M10B.

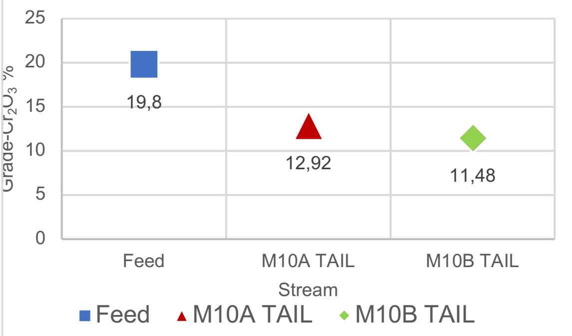

Figure 7. Chromite content in the feed and tail produce by M10A and M10B.

Figure 5 shows how the M10A and M10B were able to reduce the chromite content in the tails. This enhancement will benefit the IsaMill, which is typically used to further liberate the PGMs. When the chromite content is high, it tends to accumulate in the mill.

When the PGM flotation feed has a chromite content of 25-31%, 18% of the chromite will be recovered to the PGM concentrate, and when the feed has a chromite content of 10 -15%, the flotation recovers about 6% of the chromite (Corin, et al., 2021). Based on Figure 5, M10A tails contain 12.92% chromite, and M10B recovered 11.48% chromite to the tails. If M10A and M10B tails are used as PGM flotation feed material, chromite is less likely to report to the PGM concentrate. Each test's feed and tails were sieved to obtain several size fractions, and the chromite content of the fractions was determined using the XRF method. Figure 6 depicts the size-by-size grade results of the feed and tail, while Figure 7 depicts their mass distributions.

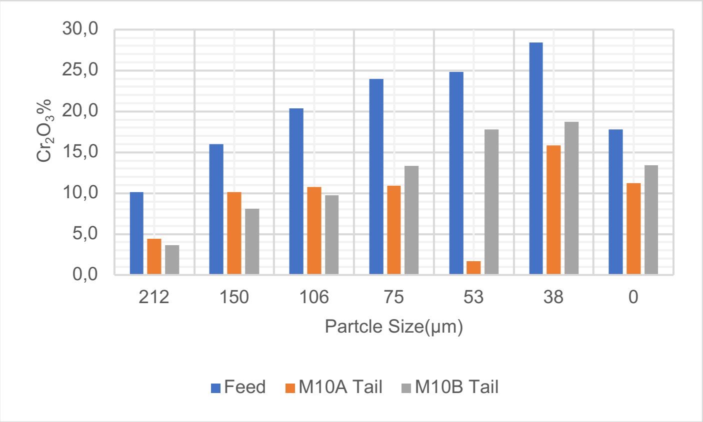

Figure 8. Particle size analyses (PSA).

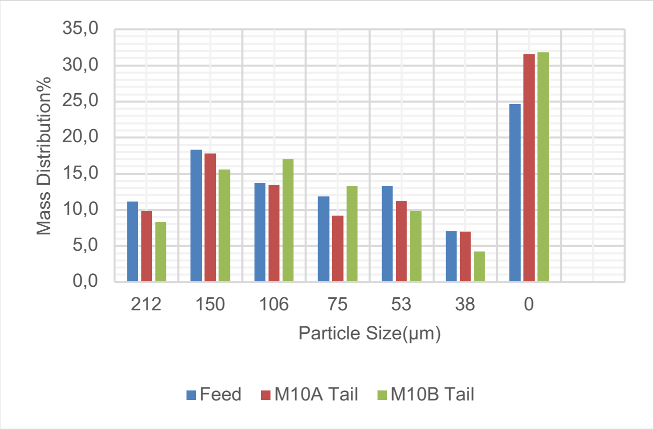

Figure 9. Particle size distribution of feed and tails (M10A and M10B).

Figure 8 compares the PSA of M10A and M10B to the feed. A lower chromite content in the tail specific sieve compared to the feed indicates that the chromite has been recovered to the middling concentrate. It has been demonstrated that the M10B is superior at recovering larger size ranges of chromite (212 µm,150 µm, and 106 µm) than the M10A, which is superior at recovering ultra-fine chromite (<53 µm). Figure 9 shows how recovering ultrafine chromite alters the material's mass distribution. On both the M10A and M10B, the mass distribution percent of the ultrafine material below 38 µm increased. Because the PGM grain size is 10 µm, this will make it easier to target the fine PGM particles, especially in the UG2 material.

CONCLUSION

The test was carried out with UG2 material that had passed through an MF2 and an 8-stage spiral plant circuit. Two MetQ ultrafine spirals (M10A and M10B) were compared to a traditional spiral (M50). According to the test results, the M50 is inefficient at recovering ultrafine particles despite being a large diameter 5 turn spiral; however, the M10A with a smaller diameter and fewer turns outperformed it. The recovery of ultrafine chromite with either an M10A or an M10B improves the material's PGM grades. The ability to manage large tonnages is what distinguishes the M10B. It was discovered that the M10A recovers chromite 53 µm very well, whereas the M10B recovers chromite in the larger fraction (212-106 µm) effectively.

Based on the results of the test, it can be concluded that these two spiral models (M10A and M10B) can be coupled and used together in certain operations. The test was based on the rougher stage - additional stages can further upgrade the PGMs and recover more of the ultra-fine chromite.

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