Experiences in the production of metallurgical and chemical grade UG2 chromite concentrates from PGM tailings streams

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Synopsis

Recovery of a chromite concentrate from UG2 flotation tailings streams, of a grade suitable for further pyrometallurgical treatment for the production of ferrochrome, has certain specific challenges not only by virtue of the decoupled nature of the primary PGM recovery process and secondary gravity based chromite recovery circuits, but also because of intrinsic variations in the nature of the ore and its mineral composition. Variability in the ore, together with upstream process dynamics, creates a challenging environment in which to achieve optimal recovery of a gravity concentrate with accurate grade control.

This paper examines certain interrelational aspects between the ore gangue and chromite mineral types, the influence of the primary PGM extraction circuit and secondary chromite extraction activity as applied specifically to UG2 ore against a background of actual plant experiences and circuit configurations applied in order achieve a suitable quality of chromite concentrate.

Keywords

UG2 chromite, spiral concentrators, chromite beneficiation

Background

Though historically chromite ore use as smelter feedstock for the production of various grades of ferrochromium has tended to favour discretely sized lump and chip materials as opposed to finer grained sand concentrates, progressive development of a variety of pretreatment processes prior to smelting (pelletizing, sintering and prereduction[1]) has resulted in refocused attention on oppor tunities in concentration of chromite in a finer particle size range (typically below 300 μm). This trend has been further expanded by the growing abundance of chromite in tailings streams from platinum production[2,3], relative to chromite ores traditionally mined specifically for their Cr_2O_3 content.

Over the past 15 years, Xstrata as a ferrochrome producer, has focused attention on a range of smelter related pretreatment processes in the interests of enhancing smelter efficiency[4], and simultaneously expanding the horizon of ore supply to include specifically fine UG2 ore concentrates to meet its growth objectives. Along with this effort has been a pioneering endeavour to produce suitable grades of chromite concentrate from a variety of tailings streams following PGM extraction.

Currently Xstrata owns and operates chromite recovery circuits on 6 different PGM concentrator plants, and cooperatively works with operators to recover UG2 chromite from a further two operations spanning the Bushveld complex. Involvement in the design, operation and optimization of such operations has been ongoing for the past 15 years, and certain of the experiences and findings relating to the extraction of chromite concentrate from UG2 tailings streams are summarized in this article.

Specifically, in the recovery of a usable chromite concentrate, either in tandem with or following PGM extraction, has been found that over and above the regular safety and economic imperatives relating to efficient plant operation and optimized recovery, the operation of such UG2 plants have at least a further two dimensional input. This is a consequence of both the nuances associated with upstream milling and flotation operations, which respond to variations in mined ore and acutely target PGM recovery, there is only incidental regard for certain effects that such activities may have on the downstream chromite recovery operations. Secondly, there is the impact of dynamic quality demands associated with the downstream smelting process.

The downstream energy intensive smelting process has specific sensitivities to firstly, controllable aspects (primarily the presence of SiO_2 rich, ferruginous gangue contaminants) and secondly, the inherent composition of the chromite spinel (Cr_2O_3 content and Cr/Fe ratio).

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It should be recognized that whereas the Bushveld complex represents a significant source of chromite in global resource terms, when viewed in a global context, chromite ore from the Bushveld complex generally represents chromites with among the lowest Cr/Fe ratios and relatively low Cr_2O_3 content in the chromite spinel itself. From among the multiple chromite seams of the complex, the UG2 seam has a specifically low Cr/Fe ratio together with relatively low Cr_2O_3 content. The low Cr_2O_3 content and Cr/Fe ratio inherent in UG2 ore, combine in rendering such ore fundamentally less attractive in its use for the production of ferrochrome compared to seams traditionally mined for their chromium content. This makes accurate grade control of the chromite concentrate particularly important.

Balancing downstream chromite ore quality requirements against a background of upstream PGM recovery imperatives

Although both Cr_2O_3 content and Cr/Fe ratio are relatively fixed for a given chromite spinel, the virtual absence of chromium in mineral species apart from the chromite spinel and the low tolerance for SiO_2 within the spinel phase itself, together with the differential density characteristics of chromite and SiO_2 rich gangue phases, creates the potential for successful and accurate separation of these phases using gravity techniques—specifically spiral concentration as applied in numerous other similar situations[3,5,6].

Historically such spiral circuits have been typically installed at one of two points in the circuit as indicted in Figure 1 (locations 1 or 2), but with most instances in more recent two stage mill-and-float (MF2) type PGM circuits having the spiral gravity circuit located downstream of the secondary float stage (location 2).

Of specific relevance in the discussion to follow, is the impact that such location has on the particle size distribution of material presented for separation across the spiral circuit.

An indication of this type of difference in particle sizing of approach slurry stream for locations 1 and 2 is given in Figure 2.

As indicated above, the relative position of the point of extraction of UG2 chromite has a significant impact on the size distribution of the feed material presented to the spiral plant.

Advances in the fundamental modelling and practical design of spirals[7,8,9] have given rise to significant improvements in the helical sluice profile adapted to specific feed types. This particularly includes finely sized slurry feeds, enhancing the ability to perform separation at finer particle sizes. However, the clear progression towards generally finer particle size ranges, as denoted by the location 2 profile in Figure 2, and likely further general movement in this direction in interests of optimizing PGM recovery[10,11], implies a corresponding verge towards the lower end of the generally accepted range of applicability for conventional commercial spirals, as indicated in the Figure 2 inset. This complicates accurate discrimination between chromite and silicate phases on the spiral section.

Briefly considering the mineral phases present in typical UG2 tailings, a dominance of chromite spinel is typical together with significant amounts of SiO_2 rich gangue minerals, primarily pyroxenes and plagioclase and a range of minor mineral phase. These are indicted by a variety of authors[12,13,14], and which can be grouped broadly as follows:

- Chromite (typically around 60% of the ROM mass), with major silicate gangue minerals being
- Orthopyroxene [(Mg,Fe)O. SiO_2] and clinopyroxene [(Ca,Mg,Fe)O.SiO_2] (some 30% of the ROM mass and

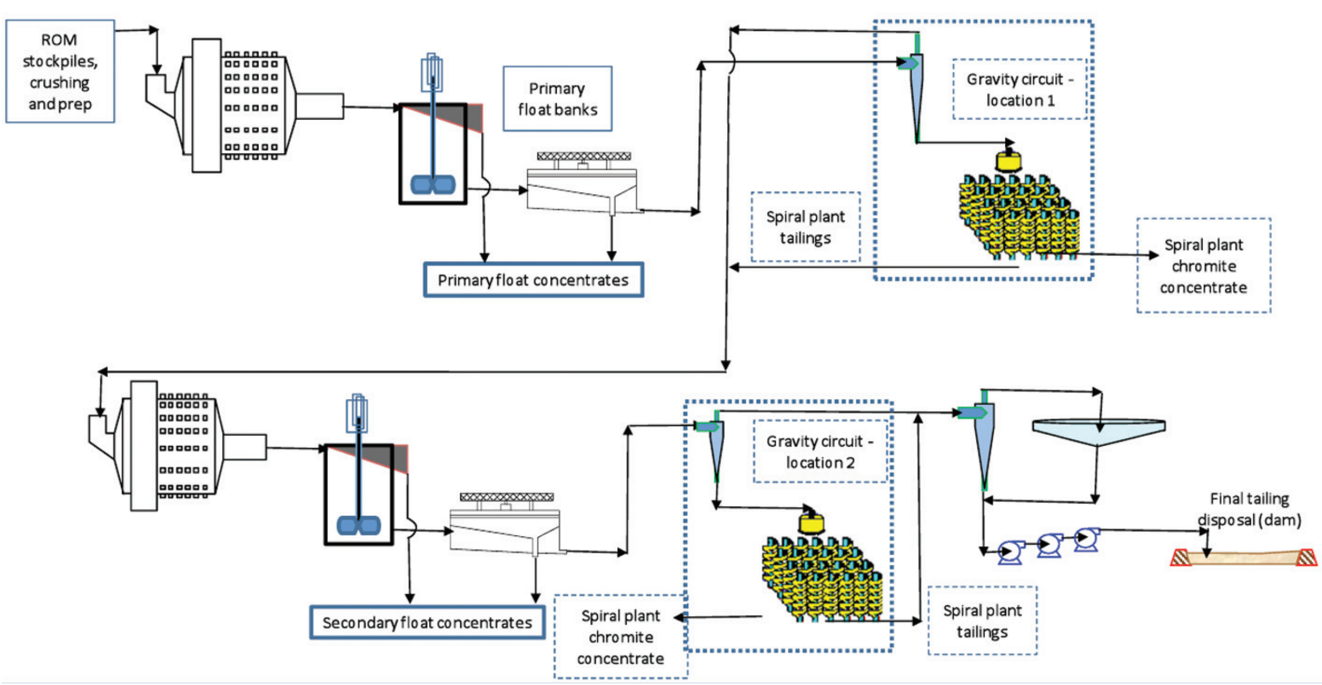

Figure 1—Outline of alternative processing circuits

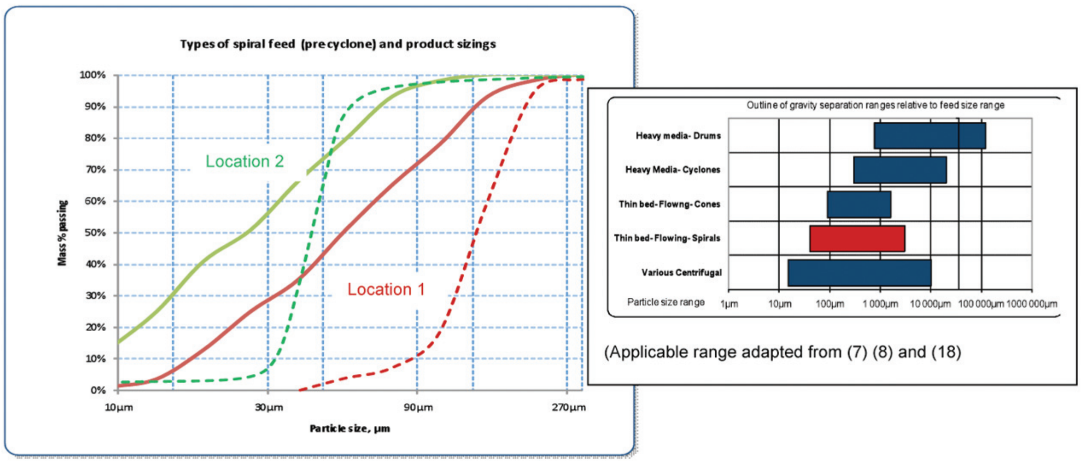

Figure 2—Outline of typical particle size distributions of the spiral plant feed stream (location 1 and location 2)

Table I

Generic chemical analyses of principle mineral phases present—used for simulation

Mineral species	FeO	Cr_2O_3	SiO_2	Al_2O_3	MgO	CaO	MnO	Total
Orthopyroxene	18.50	0.21	53.33	1.04	25.10	0.78	0.30	99.26
Plagioclase	0.74	0.10	53.40	29.34	0.44	14.75	0.25	99.02
Clinopyroxene	6.20	0.38	51.69	1.76	17.16	22.24	0.17	99.60
Chromite (end member)	28.59	44.79	0.00	16.11	9.84	0.00	0.30	99.63

Table II

Outline of UG2 chromite concentrate—western belt typical

Mineral species	FeO	Cr_2O_3	SiO_2	Al_2O_3	MgO	CaO	MnO	Total	Cr/Fe
UGS Met grade (L)	27.10	41.00	3.80	15.95	10.20	0.54	0.28	98.87	1.332
UG2 Met grade (U)	27.00	41.75	3.40	15.85	10.30	0.50	0.25	99.05	1.361
UG2 Chemical grade (L)	26.90	42.70	0.90	15.80	10.40	0.30	0.20	97.20	1.397

➤ Plagioclase [(CaO,Fe)O. SiO_2.Al_2O_3] (around 10% of the ROM mass) with much smaller amounts of talc and other mineral species

Statistical analysis of suites of spiral feed and product sample analyses, and analysis of sets of specific mineral phase data from the literature, enabled a typical compositional characterization of the slurry as it passes though the spiral plant. This facilitates an extent of fundamental modelling and improved understanding of the sensitivity of the circuit to specific feed circumstances.

From such work, a set of characteristic compositions for mineral 'end member' species can be constructed (Table I). These, together with a target final product composition (based on a specified SiO_2 content as indicated in Table II), assist in modelling and characterizing the spiral circuit.

Using SiO_2 and Cr_2O_3 content as reference dimensions to gauge compositional movement in the slurry, the Figure 3 provide an indication of the typical compositional changes in the feed and product streams with a measure of the progressive changes that take place in the slurry as it passes through the spiral circuit.

The graphs in Figure 4 are taken from composite data over a period of time, the relatively linear behaviour of chemical composition as a function of SiO_2 can be clearly seen.

The distinct objective is to maximize Cr_2O_3 unit recovery and minimize SiO_2 content in the gravity product. This has the added benefit of maximizing Cr/Fe ratio in such concentrate. A relatively minor occurrence of PGM species occasionally is found in close interstitial location surrounded by chromite[18]. The bulk of residual PGM species in the tailings is typically associated with silicate phases[12] (particularly in the coarser fractions as indicated in the work of Rule *et al.*[7,8]—summarized in Figure 5). Chromite extraction, particularly from the tailings stream therefore does not hold any negative implications for PGM recovery, but rather can offer the potential for enhanced tertiary PGM recovery[19].

Generalized characteristics of a UG2 gravity concentration circuit

The typical spiral recovery circuit used for the recovery of a chromite concentrate comprises typically at least two (in

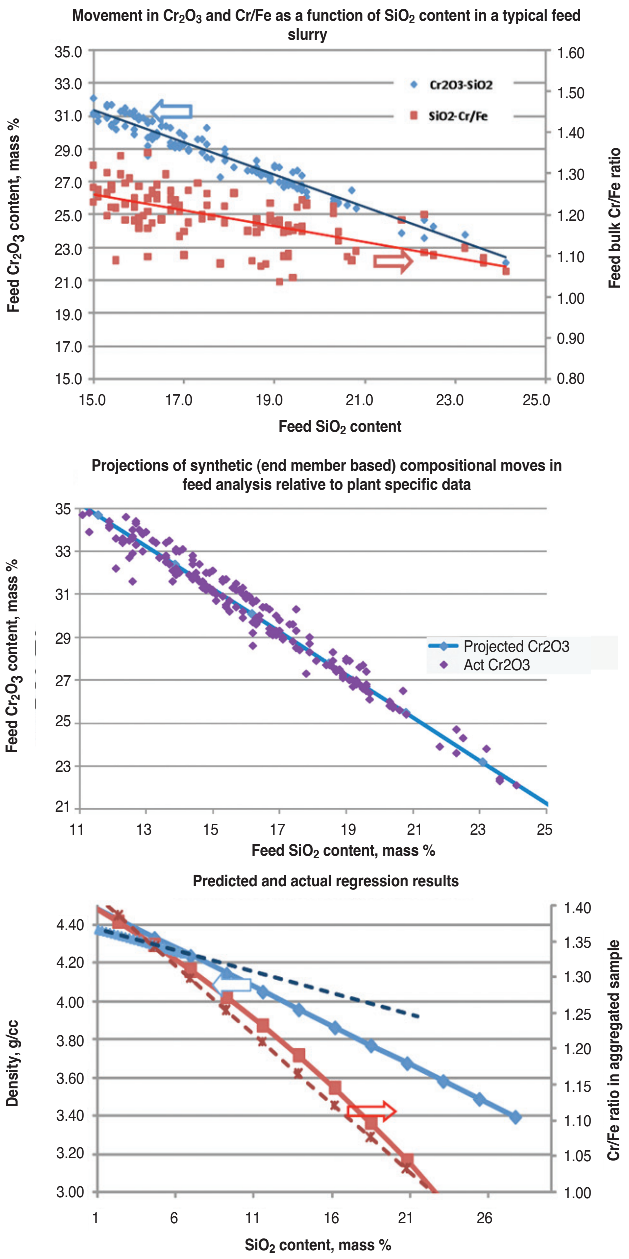

Figure 3—Outline relationships between tailings Cr_2O_3 content and Cr/Fe ratio as a function of SiO_2 content

many instances, three) sequential stages of spiral processing. These are typically roughing, cleaning and re-cleaning with various configurations around scavenging circuits, as indicated in the Figure 6. Whereas the sequence of primary and secondary separation is relatively standard, tertiary cleaning is often a practical solution implemented in cases where either relatively low or variable grade feed is routinely encountered.

Although the configuration of spiral circuit, particularly when taken in conjunction with the upstream PGM recovery circuit, has its own response characteristics, an indication of the influence of certain significant variables on performance can be tracked through the plant to establish a characteristic of the overall spiral recovery function.

Among the variables that have been found to specifically influence the overall performance characteristic are the size

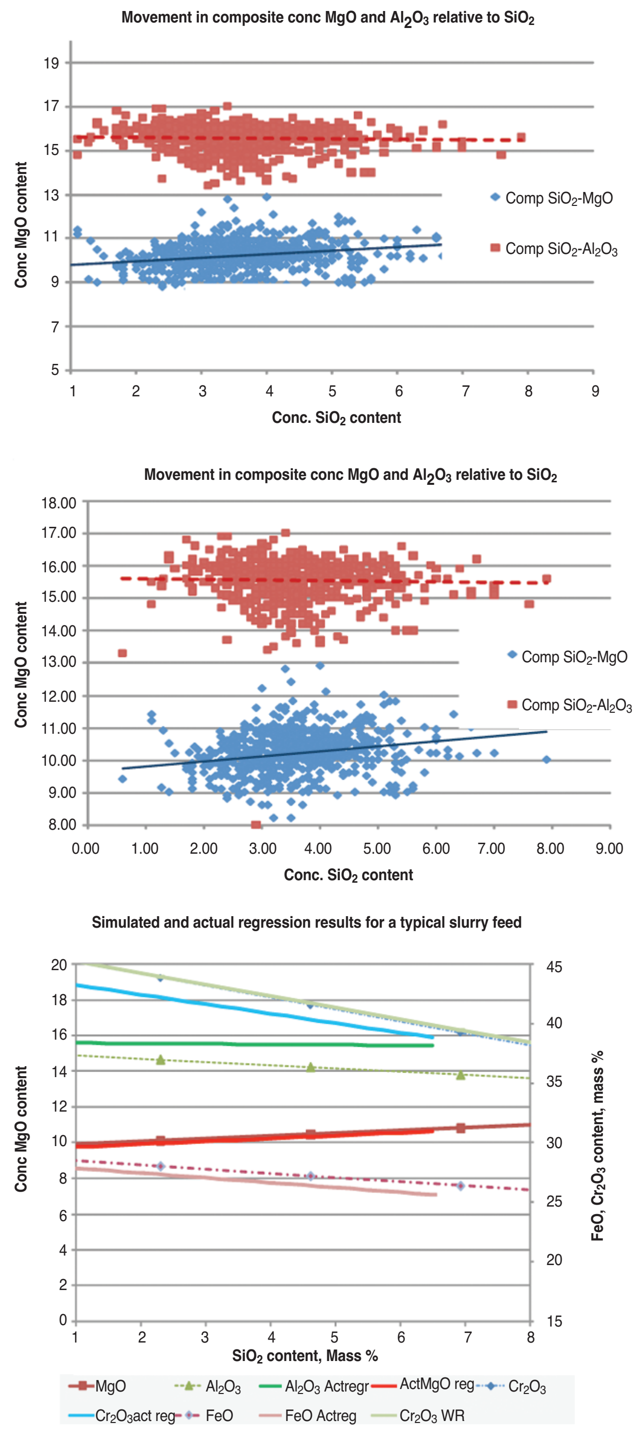

Figure 4—Composite figure showing measured and predicted compositional shifts relative to SiO_2 content in a concentrate stream

distribution along with specific mineral species deportment across the size ditribution and chromite head grade (as indicated by feed Cr_2O_3 content). An indication of the progressive movement in these characteristics across the spiral plant is indicated in Figure 7.

Figure 8 combines the data trends in adapted spiral[20,9,8,21] and aggregated circuit[22] models, one can derive a picture of the overall circuit response as a function of a variety of key operating variables such as feed Cr_2O_3 content and target product concentrate SiO_2 content.

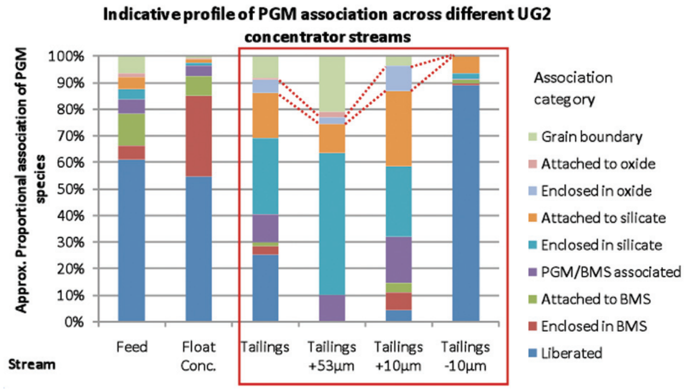

Figure 5—Primary PGM association in different feed streams (including data from Rule *et al.*[10])

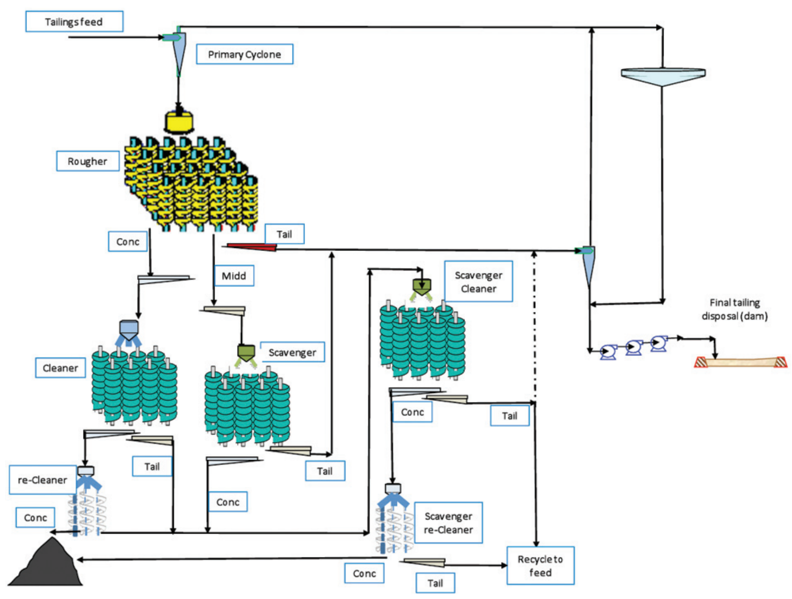

Figure 6—Outline of a basic spiral recovery circuit typically associated with treating PGM plant float tailings

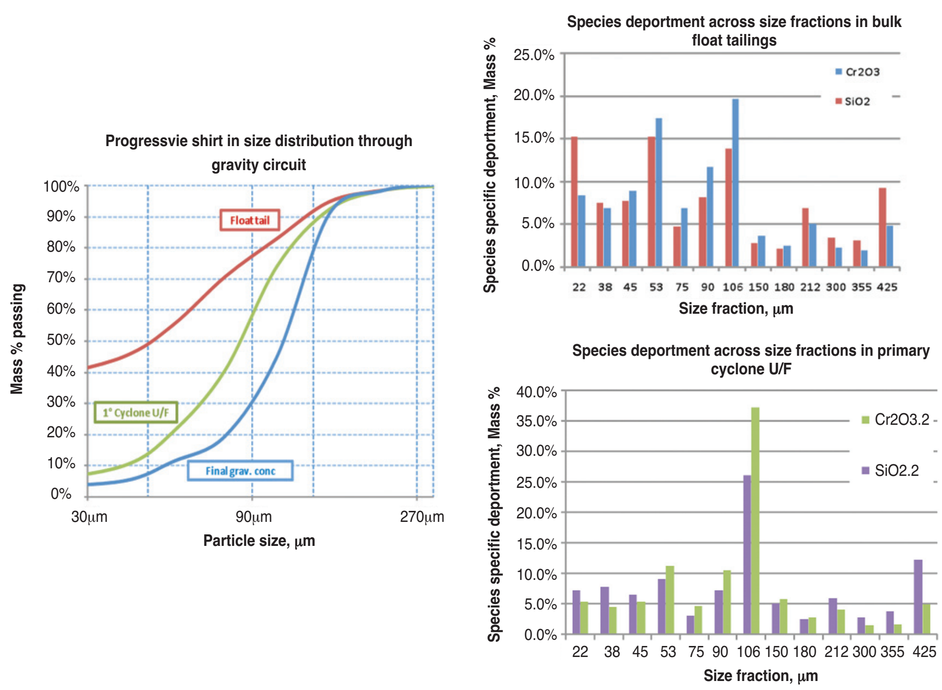

Figure 7—Indicative trace in aggregated size distribution effects across the spiral plant, together with approach species deportment profiles

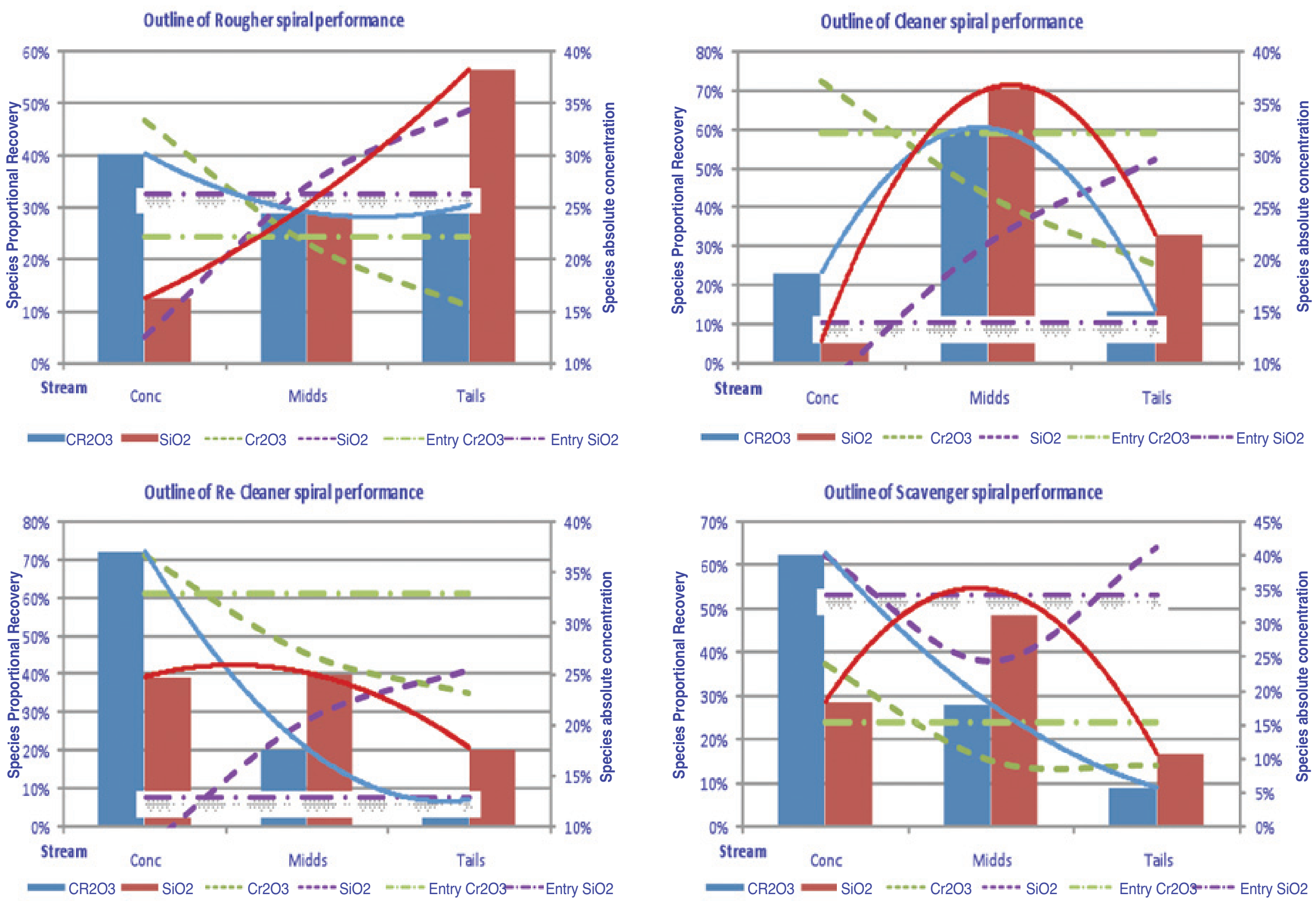

Figure 8—Outline trends in compositional response of streams across a spiral circuit

The surface presented in Figure 9 is such a modelled circuit response, representing a somewhat idealized grade-recovery surface. Correlation of such surface with actual plant data has been found to be robust in the central regions of the surface, but limited, statistically valid plant data towards the edges of the field surface show distinctly the same trend, but with numerous other factors influencing the actual performance characteristic at these extremes.

Reflections on real plant influences

With reference to relatively idealized, stable operating conditions used as the basis for deriving a performance surface, as indicated in Figure 9, actual plant performance over extended periods of time are typically more complex: there are perturbations in flow rates, and particle sizing and periodic shifts in key Cr_2O_3 and SiO_2 size-deportment profiles are not uncommon. An important point in this contextis that the upstream circuit has an exclusive prerogative in terms of PGM recovery, rather than any modulation in terms of subsequent Cr_2O_3 recovery intentions.

An indication of the potential perturbation that can be experienced in a real circuit is indicated in Figure 10, with the trace lines indicating recorded solids mass flows figures over a 4-hour moving average over a three-week period of relatively typical plant operation.

Considering that while the dynamics in solid mass flow is itself important, the fluctuation in reality is also accompanied with inevitable fluctuations in slurry composition (i.e. proportions of major mineral species) and density, as well as sizing and potentially species deportment across size fractions. The compounded influence of these variables, and the relative timescale in which variations can occur, yield a fundamentally challenging environment in which to achieve optimization of any in flight spiral separation operation.

The option of introducing specific control strategies to counter this effect remains a possibility, with innovative concepts emerging[23]. However, accurate discrimination of conditions within individual spiral stages, long lag times in calibrated analysis response feedback, and the relatively complex interactions between these parameters presents a significant challenge to the implementation of a robust adaptive control solution.

The overall result of such perturbations is thus a general decline in separation efficiency if a particular target grade (maximum level of SiO_2) is to be consistently maintained. The magnitude of this decline in efficiency can be roughly projected only onto a grade recovery surface. Such a trend, indicated in Figure 11. This might in a broad sense be considered a realistic lower boundary performance surface.

The real performance of a circuit might be anticipated to rest somewhere between these surfaces, depending on circuit configuration, feed consistency, and overall response time.

In practical terms, the consequence is an effective restriction on recovery volumes where stringent adherence to low levels of SiO_2 is typically required, for example in attempting a persistent high grade metallurgical product or even a chemical grade product with SiO_2 levels of below 1%.

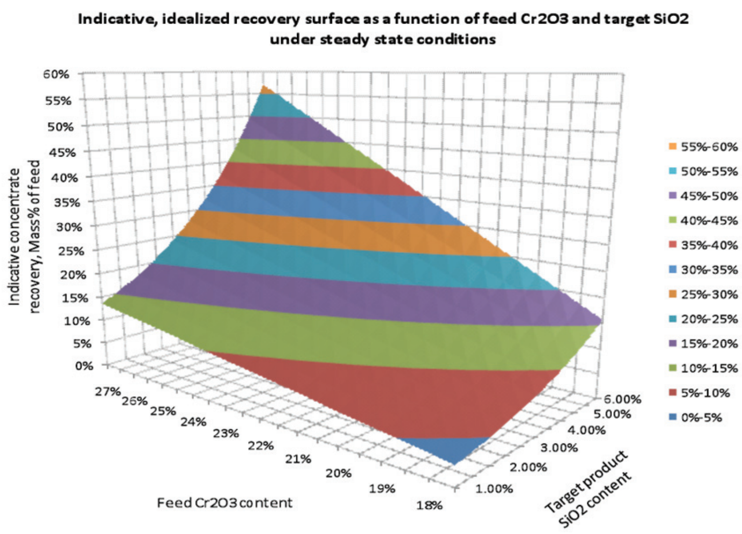

Figure 9—Idealized grade-recovery surface for a typical western belt UG2 feed

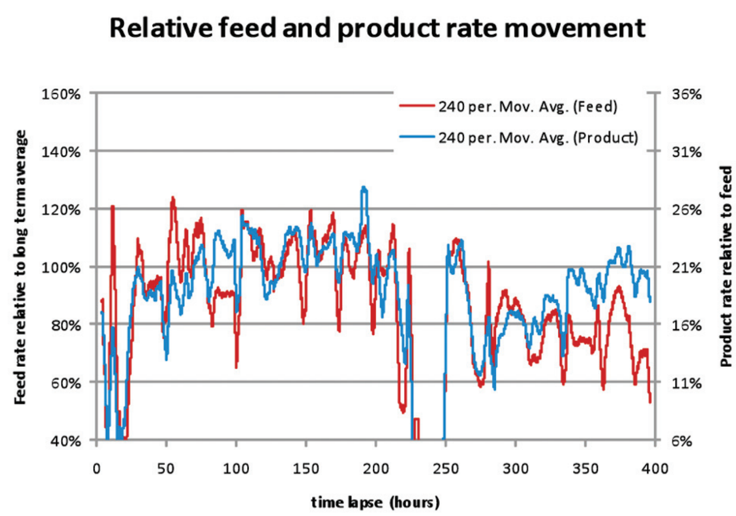

Figure 10—Outline of variations that can be periodically experienced in tailings feed

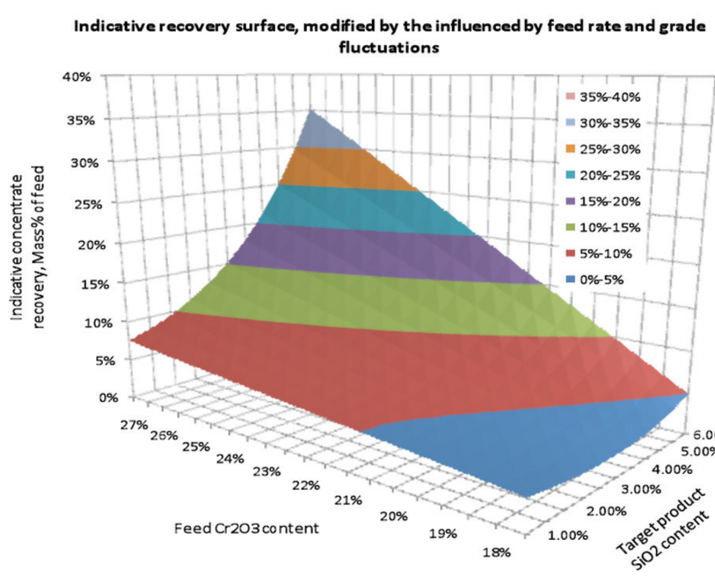

Figure 11—Grade-recovery surface reflecting efficiency related to feed perturbations

Conclusion

The large-scale exploitation of UG2 chromite for PGM recovery has an undoubted and evolving potential for considerable UG2 chromite recovery. The bulk of this separation effort will in all probability remain firmly in the realm of spiral separation, which creates a vibrant development opportunity for design and control refinement in the area.

In conjunction with relatively fundamental aspects of sluice profile design and control aspects, which target enhancement of the accuracy and efficiency of spiral performance, in this instance specifically for chromite recovery, trends in the development and refinement of tertiary PGM recovery techniques will undoubtedly play a role in extending the benefits derivable from UG2 chromite extraction. They will likely pave the way for application of such techniques to facilitate exploitation of other chromite seams, until now considered unattractive on account of either structural character (seam width) and/or fundamental chemical composition (low Cr_2O_3, Cr/Fe ratio and low PGM content).

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