Case study: high capacity spiral concentrators

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Synopsis

Spiral concentrators are compact, cost-effective and generally efficient gravity concentration separators for a wide range of applications (for example: coal, beach sands, iron ore, chromite and tantalite). Large mineral processing plants consist of thousands of spiral concentrators resulting in large plant footprints (capital intensive) and the adjustment of splitters is time consuming, impractical and is in many cases neglected—high capacity (HC) spiral concentrators aim to address these shortcomings. As a result Exxaro Namakwa Sands is currently investigating high capacity spiral technology for the spiral circuit upgrade at the primary concentrator plants (PCPs). This article summarizes the rougher spiral performance evaluation that was conducted on different types of spiral concentrators (the traditional MG4 spiral concentrator and the high capacity (HC) spiral concentrator) under different feed conditions. In addition, the effect of slimes on the spiral concentrator performance was also investigated. Slimes rheology was linked to the poor concentrator performance at the higher slimes concentrations. The test campaign shows a sacrifice in recovery under design-feed conditions can be expected when using high capacity spiral concentrators in the rougher stage when compared to traditional spiral technology currently in use. Both spiral concentrators show a detrimental impact of slimes on the performance, but the high capacity spiral concentrator is more sensitive to the higher slimes conditions.

Keywords

Spiral concentrators, high capacity spirals, slimes, heavy minerals.

Introduction

Spiral concentrators are gravity separators usually separating particle sizes between 0.1 and 2 mm in a water carrier medium[1,2]. The capacities of the spiral concentrators range between 1 and 3 t/h dry solids and recently in excess of 7 t/h in the case of high capacity spiral concentrators when treating typical heavy mineral beach sands deposits[3]. The spiral concentrators are usually configured in 5 to 7 turns and can accommodate up to four starts per column.

Spiral concentrators have been part of the minerals processing industry for the past 50 years[4]. The technology is fairly simple, relatively inexpensive and well established for pre-concentration application in mineral sands and coal industries for treating fine ore. Developments over the years include; improved feed box and splitter designs, trough design, wash water addition, capacity improvements, re-pulpers and product boxes[1]. Some disadvantages of spiral concentrators are: low throughput per unit (requiring large banks of spiral concentrators and large footprint, resulting in high capital processing plants); operation difficulties (especially cleaning the troughs and setting the splitters); sensitivity to feed fluctuations (the splitters need to be adjusted as feed conditions change); and large recycles due to inefficiencies. Recent trends are looking at high capacity units and automated splitter adjustments.[5,6]

As heavy mineral producers move into treating more difficult-to-treat low grade ores, concentrator plant capital cost and separation efficiencies become critical to the viability of processing the mineral deposit. Multistage processing and high recirculation loads are required to maintain high mineral recoveries of above 90% at mineral grades usually above 90%—typically 4 to 5 stages being the norm for the Exxaro and Richards Bay Minerals operations[3]. Concentrator plants are usually sized to a predetermined output and grade of mineral concentrate. Thus, the feed grade, determines the size of concentrator plants

Traditional spiral concentrators such as the MG4 can operate in the range of 1.6 to 2.6 t/h (solids) at 35% solids by mass in slurry feed. In contrast high capacity spiral concentrators (HC) can operate between 4 and 7 t/h at similar feed densities (% solids)[3,6]. Four MG4 spiral concentrators have a footprint of approximately 1.5 m x 1.5 m whereas four HC

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spirals have a footprint approximately 2 m x 2 m—therefore, by employing high capacity spiral concentrators, concentrator plants may be able to reduce plant footprints. But at what cost?

Plant design and spiral selection may also be influenced by the mining methods. For example, if you have an excavator or monitor gun, a smaller footprint lower capital plant would be ideal. However, if your mining method is by dredging, then it is easier to accommodate a wide, flat structure.

The aim of the study was to compare performance of the MG4 spiral concentrator with a high capacity spiral concentrator (HC) for various feed conditions and to evaluate the effect of slimes on the recovery of zircon when using these spiral concentrators in a rougher duty.

Experimental

Feed sample properties

A test sample of 500 kg was sourced from the rougher spiral feed from Exxaro Namakwa Sands operations. The sample was deslimed (slime defined as the -45 μm fraction), dried at 120°C for 8 hours and screened at 1 mm—the mineralized portion of the ore is below 1 mm. The -1 mm fraction was then split using rotary dividers into representative sub-samples of 15 kg each. This was to ensure that representative samples were available during make-up for the individual spiral concentrator tests. A head sample was also taken during the feed preparation process. Slime was sourced from thickener underflow stream during the desliming process—the slimes were added when the influence of slime concentration on separation was evaluated.

Analytical methods

Sink-float analysis

Sink-float analyses were conducted in glass separating flasks using tetrabromoethane (TBE) as a medium with a relative density of 2.9. Up to 500 g of sample was added to 500 ml of TBE, thoroughly mixed and allowed to stand, allowing material heavier than 2.9 g/cm^3 to sink. This was repeated three times and then the material heavier than 2.9 g/cm^3 (sinks) was removed through a valve at the bottom of the separating flask. The floats and sinks were washed with acetone to remove any residual TBE. These samples were then dried and the percentage sinks and floats quantified.

Qemscan® analysis

Qemscan® particle mineralogical analyses (PMA) were performed on the sink fractions to quantify the mineral species. The Exxaro developed sip (species identification protocol) file was utilized for the identification and quantification of the mineral species. 2000 grains on a 5 μm grid spacing were analysed per sample.

Density determination of slime-containing water to predict the slimes content of the water

In order to perform in-time adjustments of the slimes concentration in the spiral feed, a relationship had to be established between the density of the slime-containing water and the concentration of slimes in the water. For this purpose a 250 ml volumetric flask was calibrated with water at a RD of 1. Slime slurry was screened by employing a 45 μm laboratory screen. The -45 μm fraction was thoroughly mixed and the density measured using the calibrated 250 ml volumetric flask. The flask was weighed in grams to the nearest second decimal. Individual data validation tests were conducted by drying the solids after density measurements to determine the % solids in the slurry—this was compared to the calculated values. The relationship shown in Figure 1 was developed for ease of measurement during a campaign—the relationship shows the mass % slimes in the spiral feed by measuring the density of the water containing slime (at 35% solids in feed to the spiral). The relationship in Figure 1 is applicable only at the feed conditions specified. At different feed conditions, the relationship would have to be recalculated using the volumetric flows.

X-ray diffraction analysis

Samples were pulverized in a tungsten carbide milling vessel. X-ray diffraction analysis was conducted using a PANalytical X'Pert pro powder diffractometer with X'Celerator detector and variable divergence and receiving slits with Fe filtered Co-Kα radiation. Semi-quantification was done using Panalytical X'Pert Highscore analytical software.

Experimental set-up

Experiments were carried out on a closed-circuit test rig comprising a pump, variable speed drive (VSD), mouth-organ splitter, a chinese-hat distribution box and the spiral concentrator. There are two exit streams from the distribution box—one feeds the spiral concentrator and the other is a return line to the sump. The return is positioned in such a way that it agitates the material in the sump.

The current primary concentration plant (PCP plant) at Exxaro Namakwa Sands is fitted with MG4 spirals in the rougher circuit. A HC test unit was available at Exxaro R&D for test work. Both spirals are supplied by Downer EDI. The two test spiral concentrators (MG4 and HC) were fitted with a mouth-organ splitter and swing sampler (see Figure 2) that were able to divide the cross-profile of the spiral into seven splits. Seven cuts were sufficient to produce a representative and continuous release curve. Water and feed material were added to the sump to achieve the desired feed density

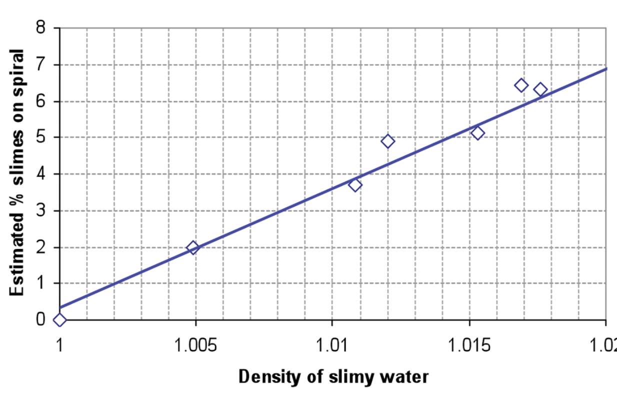

Figure 1—Experimental relationship of the density of slime-containing water as a function of the % slimes (by mass) feeding the spiral concentrator

(a)

(b)

Figure 2—Components of the equipment set-up are depicted in the mouth-organ splitter (a) and the pneumatic sampling point (b)

Table I

Test matrix detailing the range of tests conducted when comparing the selected spiral concentrators

Test conditions for MG4 spiral							
Test no.	**Feed rate (t/h)**	**Feed concentration (%solids)**	**% slime in spiral feed**	**Test no.**	**Feed rate (t/h)**	**Feed concentration (%solids)**	**% slime in spiral feed**
Feed rate variation (t/h)				**Feed slimes variation (mass % slimes)**			
1	1.5	35	5	5	2	35	2
2	1.75	35	5	6	2	35	4
3	2.0	35	5	7	2	35	5
4	2.2	35	5	8	2	35	7
Feed grade variation (% THM)				**Feed concentration variation (% solids)**			
9	2	35	5	13	2	37	5
10	2	35	5	14	2	40	5
11	2	35	5	15	2	42	5
12	2	35	5				
Test conditions for HC spiral							
Feed rate variation (t/h)				**Feed slimes variation (mass % slimes)**			
16	4.5	35	5	20	5	35	2
17	5.0	35	5	21	5	35	4
18	5.5	35	5	22	5	35	5
19	6.0	35	5	23	5	35	7

During testing only a single parameter was changed, all other variables were kept constant as far as practical possible. The bold numbering indicate the variations of the specific condition

(expressed as % solids by mass) and flow rate (t/h) required per test. Once the desired parameters were obtained, two or three samples were taken to investigate stability of the flow conditions on the separation trough. This was done by sampling the entire spiral profile at once. The slurry was weighed and then the water was decanted. It was inferred that when the water is decanted from the slurry sample, the remaining solids contained 20% moisture (this value was confirmed prior to the actual test by drying the solids after decantation). The samples were subsequently returned to the system and the procedure repeated two-more times. This was to ensure that the system was stable and the desired conditions reached. Once stable conditions had been obtained a sample of 7 cuts was taken. Between 35 and 80 kg of feed sample was required to the reach desired tonnages of 1.5 to 7 t/h for the various tests.

The spiral concentrator comparison was based on feed-rate (t/h), slime content and feed grade (mineral content) variation.

Experimental test conditions

A test matrix detailing the conditions tested is provided in Table I.

Slimes addition

Slime content was increased by adding material originated from the thickener underflow to the sump. It was assumed that the recirculation of this material would break up any flocculant in the thickener underflow. Slimes content of the slurry stream was determined by the density measurement of the slimes-containing water as described earlier.

Recovery calculations

Separation curves were developed for each of the valuable minerals in every experimental run conducted—see earlier for the detail on the Qemscan analysis. The separation curve is a plot of cumulative mass % mineral recovered as a function of the cumulative mass % recovered across the spiral profile starting from the part of the mouth-organ splitter closest to the centre column. Of all the valuable minerals only zircon is used for illustrative purposes in this paper (as shown in Figure 3). Zircon recoveries were determined by utilizing the separation curves and used for comparative purposes as discussed in the remainder of this study—only the 30% mass recovery value was used. The value of 30% was selected as an arbitrary point. In the PCP up to 50% from the rougher circuit can report to concentrate and middling. It is important to reject as much mass as possible to tails in the rougher circuit with little mineral lost to tails.

Results and discussion

Feed sample characterization

Table II is a summary of the spiral feed that was tested. Zircon, rutile and ilmenite made up only 32% of the sinks.

This shows that there is a large amount of uneconomical heavy minerals present in the feed. The RDs of ilmenite, rutile and zircon are between 3.9 and 4.5 and that of quartz (is approximately 2.6). Table II is a summary of the spiral feed that was tested. Zircon, rutile and ilmenite made up only 32% of the sinks.

The feed material was sized between 1.0 mm and 0.05 mm—thus the feed was suitable for spiral separation (correct size range and adequate density differences: $\Delta G > 1$)[2].

Zircon and ilmenite were fairly well liberated grains (see Figure 4). Quartz particles were generally coarser than the economic minerals. Recalculating mineral content as mass% in feed gives zircon content of 0.81 mass% and ilmenite content of 2.55%.

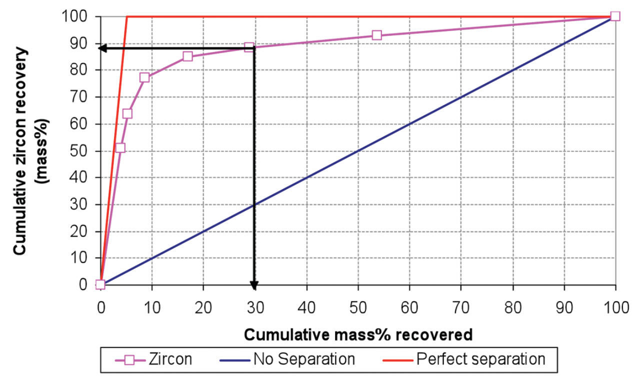

Figure 3—Separation curve showing mass percent zircon recovered as a function of mass recovered. Mass recovery was accumulated from the inside of the spiral (next to the centre column). This figure illustrates the MG4 performance at 1.8t/h and 35% solids in feed

Table II

Head sample characterization of the test sample

	Fraction	Mass %
Slime	-45 µm	0.75
Sink-float analyses @ RD 2.9	Sink	12.68
	Float	86.58
Mineral content in sinks	Zircon	6.35
	Rutile	5.66
	Ilmenite	20.11

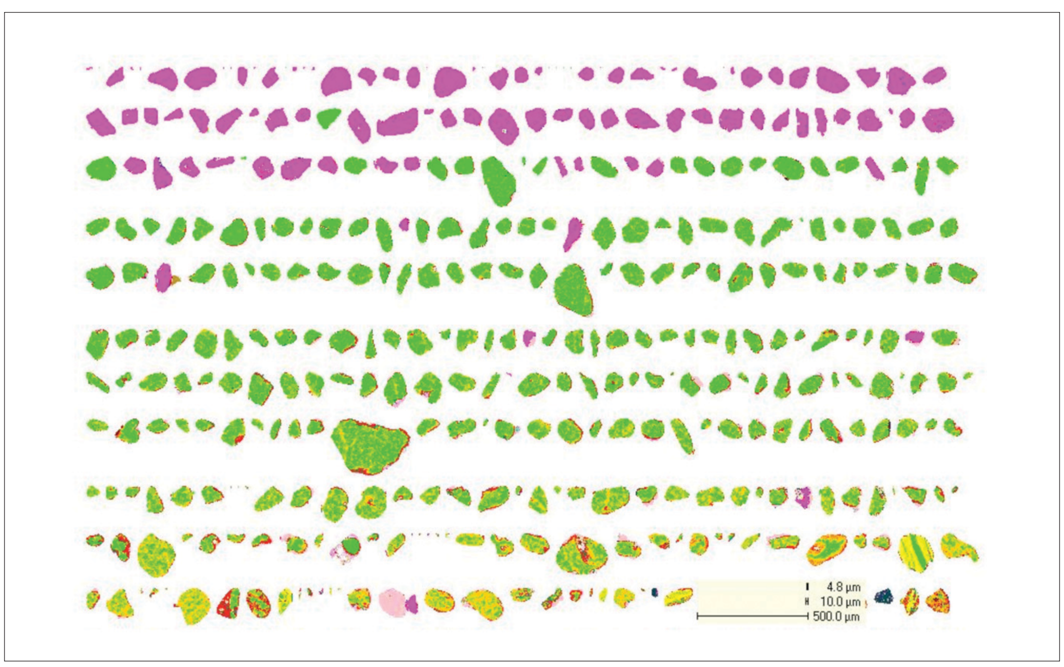

Figure 4—Qemscan particle map sorted by zircon particles (purple) on the top followed by ilmenite particles (green)

Effect of feed density at varying slimes concentrations on the performance of the MG4 spiral concentrator

As indicated from the test matrix (Table I), the feed rate for these experimental runs was kept constant at 2 t/h. The effect of feed density at varying slimes concentrations on the performance of the MG4 spiral is shown in Figure 5. For this ore type, the MG4 was able to maintain high zircon recoveries at a 30% mass recovery to concentrate when the slimes concentration by mass in the spiral concentrator feed was below 5%. However, if a slimes concentration of 6% is exceeded the zircon recovery decreases sharply with an increase in the feed solids concentration. The reason for the sharp decrease in the zircon recovery is a result of the slimes affecting the viscosity of the fluid. With a higher feed density the slimes exacerbates the effect on the zircon recovery since the total volumetric flow on the spiral concentrator decreases.

Effect of feed grade at varying slimes concentrations on the performance of the MG4 spiral concentrator

As indicated in the experimental section the feed rate for these experimental runs were kept constant at 2 t/h and the feed density was maintained between 34 and 37 mass% solids. The effect of feed grade (in mass % THM) at varying slimes concentrations on the performance of the MG4 spiral is shown in Figure 6. A constant 30% mass recovery to concentrate was used to calculate zircon recovery. High zircon recoveries at above 96% were achieved with low slime in spiral feed irrespective of feed grade changes from 7% to 15% THM. At higher slime content in spiral feed (> 6% by mass) zircon recovery losses were observed.

It is unfortunate that no data were available between 9 and 11% THM in the feed for the high slime trend in Figure 6.

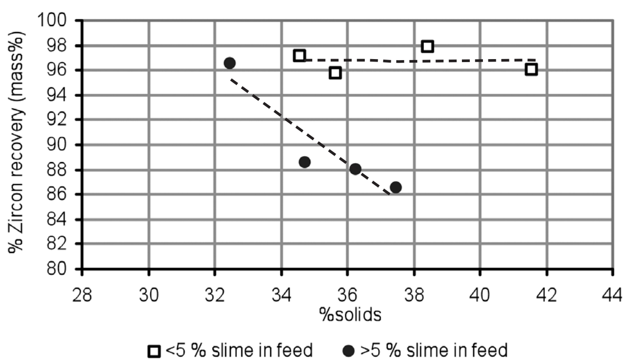

Figure 5—Effect of feed density at varying slimes concentration on the performance of the MG4 spiral concentration. Experimental runs were performed at a constant feed rate of 2 t/h

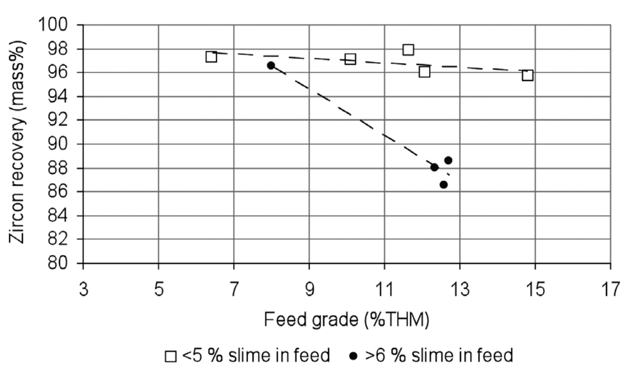

Figure 6—Effect of feed grade (% THM) at varying slimes concentration on the performance of the MG4 spiral concentration. Experimental runs were performed at a constant feed rate of 2 t/h and the feed density was maintained between 34 and 37 mass % solids

Effect of feed rate at varying slimes concentrations on the performance of the MG4 and HC spiral concentrators

Both spiral concentrators were evaluated for effect of feed rate on performance—for this campaign the feed solids concentration was kept constant. Figure 7 clearly indicates that the performance of the spiral concentrator (measured as the zircon recovery) decrease with an increase in the feed rate. The break-away point for the slime discussed earlier is clearly evident in Figure 7. For the MG 4 spiral concentrator about a 7% zircon recovery is sacrificed if the slime concentration is allowed to exceed 5%. Approximately a 5% zircon loss is experienced on the HC spiral concentrator due to the same effect. In addition the HC spiral concentrator was less sensitive for changes in feed rate provided that slimes content was below 4%. Recoveries at low slime conditions on the HC spiral concentrator were similar (recoveries around 85% of zircon) to the MG4 spiral concentrator performance at high slime conditions. Similar trends in losses due to effect of increase in feed rate were also observed by other authors[1,4–5].

Effect of varying slime in feed on the performance of MG4 and HC spiral concentrators.

Figure 8 illustrates that irrespective of feed rate similar losses can be experienced with increase of slime on the spiral concentrator. Significant zircon losses are observed as slime content in the feed is increased. Poor desliming upfront can severely negatively affect spiral concentrator performance. Typically 6% slime can report to the spirals after desliming with cyclones at Exxaro's operations. The slime portion for Exxaro's mines contains typically 20 to 40% clay minerals—hence the significant zircon losses are observed during the test work. The clay minerals have major impact on the viscosity of the carrying fluid in the spiral.

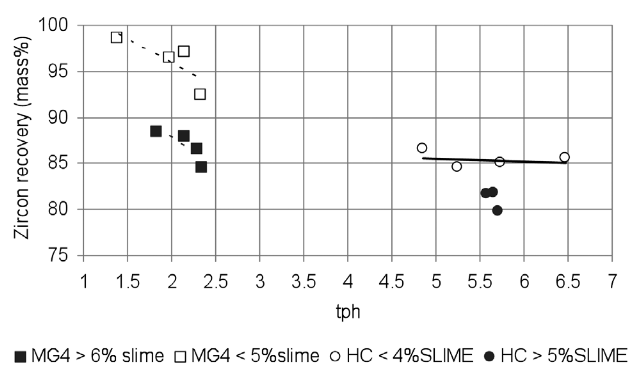

Figure 7—Effect of feed rate (t/h) at varying slimes concentration on the performance of the MG4 and HC spiral concentrator. Experimental runs were performed at constant feed density of 34 and 37 mass % solids

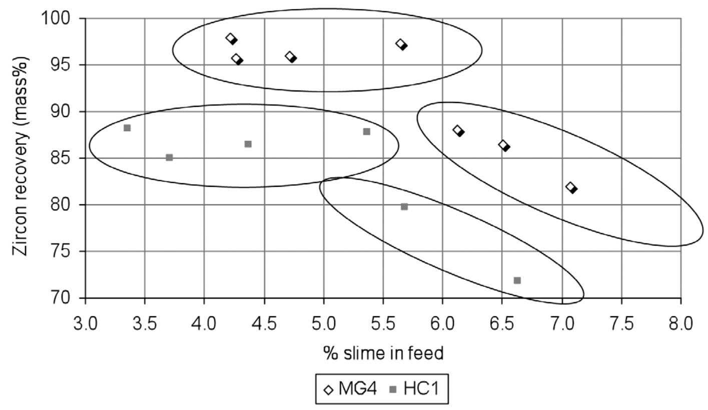

Figure 8—Effect of slime at a constant feed rate at 35% solids showing zircon recovery as a function of slime in feed to the spiral

When comparing all the data obtained during the test work campaign, it was evident that for both the spiral concentrators employed, a 'break-away' point could be identified for the amount of slimes on the spiral concentrator—this 'break-away' point indicated the point where the zircon recovery was drastically affected. For the MG spiral this point was at approximately 5% slimes by mass of the dry solids or alternatively where the relative density (RD) of the slime-containing water was 1.014 (see Figure 1). For the HC spiral the same phenomenon was evident albeit at 4% slimes by mass (RD of slime-containing water was 1.011). In order to establish the relationship between the viscosity and the density of the slime-containing water, viscosity measurements were subsequently performed. It is known that the high levels of slime adversely affect the performance of spiral concentrators[7,8]. In addition, it is known that the slimes can contain clay minerals. Some clay minerals—for example smectite—swell in the presence of water resulting in the formation of fine particle which affect the rheological behaviour of the slurry[9]. It is also known that the heavy mineral slimes can contain up to 60% smectite clays[9]. Literature shows that the slimes content of the spiral concentrator feed should be reduced to around 10% to ensure good separation[8]. However, this work indicates a negative effect even at lower slimes content. This shows that spiral performance is dependent on the mineral deposit properties—a recent investigation at Richards Bay Minerals showed high performance of the HC1 spiral.[3]

Conclusions

Mineral recovery on the HC spiral was inferior to the MG4 spiral for this type of ore. Higher recoveries were attained at lower tonnages, making the MG4 spiral concentrator more suitable for treating this type of ore. The HC spiral concentrator also showed more sensitivity to the slime content of the deposit. For every % increase in slime in feed, a 5% zircon recovery loss was observed for both spirals. The MG4 spiral was able to maintain good performance as long as the slime concentration was kept below 5%. Significant mineral losses were observed when slime in excess of 6% was encountered. The same observations were made for the HC spiral but the break-away slime point was only at 4%. The effect of feed rate increase related to mineral recovery loss is well published and similar trends were observed—some literature shows that for some ores a low slimes content in feed benefits separation. Spiral concentrator selection is dependent on ore characteristics.

Acknowledgements

The authors would like to thank Exxaro Namakwa Sands for the opportunity to publish the data present in this article.

References

1. HOLLAND-BATT, A.B. Some design considerations for spiral separators, Minerals Engineering Lake Tahoe, 1995.
2. WILLS, B.A. Wills' *Mineral Processing Technology*, Seventh Edition, Oxford, 2007.
3. GRACIE, S. Redesigning the industry standard—a new look at the wet concentrator circuit. *The 7th International Heavy Minerals Conference 'What next',* The Southern African Institute of Mining and Metallurgy, 2009. pp. 107–108, 110
4. Separation solutions, *Outokumpu Technology Physical Separation Newsletter*, issue 1, 2005.
5. RICHARDS, R.G. and PALMER, M.K. High Capacity gravity separators; a review of current status. *Minerals Engineering*, vol. 10, no. 9 1997. pp. 973–982.
6. ERASMUS, W. Personal communications, 2010.
7. ABELA, R. The effect of the slimes content on the rougher spiral circuit in a heavy mineral sands operation, *Proceedings of the Heavy Mineral Conference 2003*, 2003.
8. BROWN, R. Slimes Effect on Spiral Efficiency, Report on the Cooljarloo North Mine, 2001,
9. MORKEL, J. and VERMAAK, M.K.G. The role of swelling clay in kimberlite weathering, *Mineral. Processing and Extractive Metallurgy* (Trans. Inst. Min. Metall. C), 2006, vol. 115, no. 3, pp. 150–154.

Bibliography

1. MATTHEWS, W.B., FLEYCHER, C.A.J., and PARTRIDGE, T.C. Particle flow modelling on spiral concentrators: Benefits of dense media for coal processing? *Second International Conference on CFD in the Minerals and Process Industries*, CSIRO, Melbourne, Australia, 1999.
2. MARCOS, S.P. and GILMAN, K.S. 'Old tricks for new dogs' Areas for focus in mineral sand processing. *The 6th International Heavy Minerals Conference 'Back to Basics'*, The South African Institute of Mining and Metallurgy, 2007, pp. 55–61. ◆