

WASH WATER OPTIMIZATION ON AN IRON ORE SPIRAL

C. M. Ramotsabi, W Erasmus and F Bornman

Multotec Process Equipment (Pty) Ltd

28 Forge Road, Spartan

Kempton Park, 1620, South Africa

(Author: christinar@multotec.com)

ABSTRACT

Gravity concentration remains the main separation method for fine iron ore and is used extensively for treating various minerals. Gravity concentration methods separate minerals of different specific gravity by their relative movement in response to gravity and one or more other forces, the latter often being the resistance to motion offered by a viscous fluid, such as water or air (Wills, 2006).

Spirals concentrators are one of the gravity concentration equipment used for beneficiation of minerals. Spirals are typically used for processing of fine minerals (-1mm) size fraction. The main operating variables for a spiral concentrator are the feed rate, the solid concentration, the wash water addition and the position of the cutters or splitters used to separate the tailings, middling and concentrate streams (Sadeghi, Bazin & Renaud, 2014).

The aim of this study is to investigate the effect of feed rate, solid concentration and the wash water on grade and recovery on iron ore material. The Multotec SC20HC/7 WW spiral was used for the experimental test work. The spiral was tested at varying solid concentration and feed rate. The wash water rate was also varied to establish the best washing rate. The splitter positions were kept constant. Optimization of these variables is expected to provide optimum conditions for a good compromise between grade and recovery.

KEYWORDS

Iron ore, wash water, recovery, grade

INTRODUCTION

Spiral concentrators are simple low energy consuming devices that separate minerals mainly on the basis of density. Spirals are widely used in mineral processing as a method for preconcentration and have proven to be metallurgically efficient and cost effective.

Spirals have a wide application, they are used in iron ore processing, coal, gold, chromites, mineral sands, glass sands, and in soil cleaning.

Separation on a spiral is achieved through a combination of forces that act on particles as they move down the trough of the spiral. The main forces known to act on the particle on a spiral are the gravitational forces, centrifugal force, hydrodynamic drag, and lift and friction forces (Kapur & Meloy, 1998). Apart from the forces acting on a spiral, the properties of the slurry flowing on a spiral including, solids concentration, feed rate and wash water also plays an important role in the separation on the spiral.

The relationship between separation efficiency and feed rate was shown to be linear, with a decrease in efficiency at higher flow rates. Previous work on flow profile by Holland - Batt (1990) indicated that any increase in the feed rate to a spiral results in a greater part of the additional flow volume reporting to the outside of the trough. The flow on the outside of the trough becomes energized and consequence to that the heavy particles find it hard to settle and escape this region to the inner region. This effect has a high impact on recovery of heavy minerals, since any increase in volumetric flow on the spiral is not made available for recovery in the inner region of the spiral

Control of solid concentration on a spiral is very important as it influences separation and recovery on a spiral. Recovery on a spiral has been shown to increase with an increase in solids concentration up to a point where it is optimum and then drops at relatively high solid concentration (Richards & Palmer, 1997).

When separation is in progress on the spiral, the heavy particles migrate toward the inner region of the trough, the concentration of these dense particles becomes high and as a result the ease of flow of material becomes reduced. This bed of particles in a wash waterless spiral can prevent further separation of particles, resulting in silicates being trapped. Wash water is an important control variable used to wash away entrapped light minerals from the concentrate stream (Burt, 1984; Bouchard, 2001). The use of wash waters on spirals can be used to restore the fluidity of the material to avoid beaching and to wash away the trapped silicates (Holland - Batt, 1995). The wash water can also wash away the valuable minerals to the tailing section, Sadeghi *et al* (2014) showed that an increase in wash water rate enhances grade but simultaneously increases the loss of valuable minerals to the tailings section. Positioning of the wash water is also important; it plays a role in reducing the misplacement of the valuable minerals to the tailing stream. Positioning the wash water nozzles to the middling section of the spiral trough has been shown to enhance recovery of heavy minerals while washing away the gangue (Reddy, Krüger, Ramotsabi & Lincoln)

Emanating from the background of the study, the aim of this study is to investigate the effect of feedrate, solid concentration and the wash water on grade and recovery on iron ore material. The Multotec SC20HC/7 WW spiral was used for the experimental test work. The spiral was tested at varying feed rate and solid concentration, the wash water rate was also varied to establish the best washing rate. The splitter positions were kept constant. Optimization of these variables is expected to provide optimum conditions for a good compromise between grade and recovery.

EXPERIMENTAL

Material

The -1mm hematite sample used for this study was sourced from Kumba plant in Sishen. The sample was a low grade with an average head grade of 43% Fe. The sample was blended and a representative sample taken out for particle size distribution (PSD) determination and size by assay. The results of the size by assay of the sample are shown in Table 1. The PSD shows less than 5% of the 38micron fraction which indicates that the slime content was not significant in the sample as a result the sample was processed as is on the spirals without desliming upfront.

Table 1 – Feed Sample Size by Assay

Size(microns)	% Mass	Cumm % Retained	% Fe	Cumm % Fe	% Fe Recovery	Cumm % Fe Recovery	% SiO ₂	Cumm % SiO ₂	% SiO ₂ Recovery	Cumm % SiO ₂ Recovery
+										
1000	15.04	15.04	44.5	44.50	14.76	14.76	23.4	23.40	15.31	15.31
850	8.68	23.72	44.2	44.40	8.46	23.22	23.9	23.58	9.02	24.33
600	15.49	39.21	44.5	44.45	15.21	38.42	24.0	23.75	16.17	40.50
425	13.22	52.42	45.4	44.68	13.22	51.64	23.3	23.63	13.40	53.90
300	11.20	63.63	46.1	44.93	11.39	63.03	22.5	23.44	10.96	64.86
212	9.69	73.32	45.2	44.96	9.65	72.67	23.7	23.47	9.99	74.85
150	9.16	82.48	45.0	44.96	9.09	81.76	24.0	23.53	9.56	84.41
106	5.20	87.68	45.7	45.00	5.24	87.00	23.4	23.52	5.30	89.71
75	4.98	92.66	48.5	45.19	5.32	92.32	20.3	23.35	4.40	94.11
53	2.02	94.68	53.2	45.36	2.37	94.69	14.8	23.17	1.30	95.41
38	1.17	95.85	53.9	45.46	1.39	96.08	14.0	23.05	0.71	96.12
	4.15	100.00	42.8	45.35	3.92	100.00	21.5	22.99	3.88	100.00
	100.00		45.35		100.00			22.99	100.00	

Methods

The test work was conducted on the Multotec SC20HC spiral fitted with a mouth organ product box as shown in Figure 1. Mouth Organ (MO) fraction A represents the sample collected from the inside of the trough. It is the heaviest sample and should contain most of the Fe.

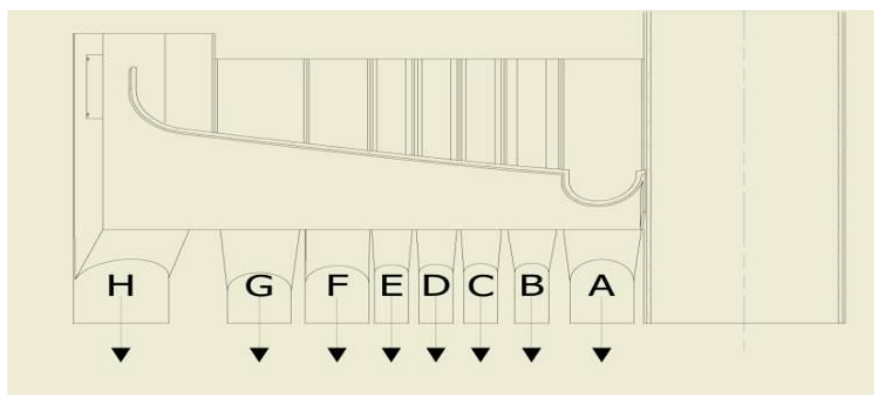


Figure 1 – Mouth Organ Configuration

The spiral was operated in closed circuit as shown in Figure 2. The slurries were fed to the spiral feed box via a distributor with an overflow to ensure constant feed conditions during the test.

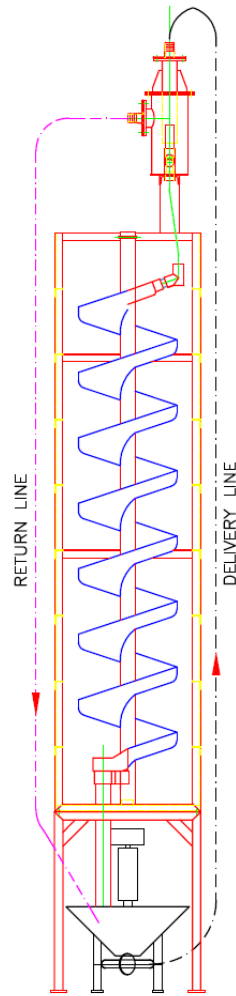


Figure 2 – Spiral test rig setup

Each spiral stage was run until steady state conditions were reached before taking the relative density (RD), solid concentration and feed rate measurements at the top of the spiral rig. Three consistent RD measurements and three consistent flow rate measurements were recorded before taking simultaneous timed samples (Fraction A to H) from the mouth organ.

The wash water nozzles were positioned closer to the middle of the trough such that the wash water does not disturb the already separated material closer to the gulley fraction; this material was allowed to flow into the splitter and directed in the gulley fraction. The positioning was also done so that the fluidization effect could assist the iron particles in the middling section of the flow to migrate to the inside of the trough. The wash water nozzles were directed against the flow to enhance the fluidization effect and to increase the mean free path of the particles. The positioning of the wash water nozzles is shown in Figure 3



Figure 3 – Wash water setup

Experimental Plan

The test plan was divided into phases. Phase 1 and Phase 2 test plans are shown in Table 1 and Table 2 respectively. Phase 1 entailed all the tests which varied slurry properties on the spiral including, the concentration, and the feed rate. The solid concentration was varied between 30 % to 40 % while the feed rate was varied between 1.6 to 3 tph. On phase 2 test plan, the feed rate was kept constant at 2 tph and only the solid concentration and the wash water rate were varied. The solid concentration was varied between 30 % to 40 % and the wash water rate varied between 10-21 l/min.

Table 2 – Phase 1 Test Plan

Variables	% Solids	tph
Test 1	30	1.5
Test 2	30	2
Test 3	30	3
Test 4	35	1.5
Test 5	35	2
Test 6	35	3
Test 7	40	1.5
Test 8	40	2
Test 9	40	3

Table 3 – Phase 2 Test Plan

Variables	% Solids	tph	WW Rate(l/min)
Test 1	30	2	10
Test 2	30	2	16
Test 3	30	2	21
Test 4	35	2	10
Test 5	35	2	16
Test 6	35	2	21
Test 7	40	2	10
Test 8	40	2	16
Test 9	40	2	21

Sampling and Analysis

Mouth organ product samples from each spiral test were collected and analysed by ICP method for Fe and SiO₂ content. The test work data and chemical analysis data were used to calculate the mass yield and the corresponding Fe and SiO₂ grade and recoveries.

RESULTS

Effect of Solid Concentration and Feed Rate on Grade

Figure 4 and 5 shows the effect of feed rate on grade and mass yield at 30 % and 35 % solid concentration respectively. The highest upgrade achieved at 30% solid concentration in the A Fraction was 51.57 %, 50.45% and 53.63% Fe at 1.77 tph, 2.05 tph and 2.95 tph respectively. Similarly the highest upgrade achieved in the A Fraction at 35 % solid concentration was 51.83 %, 50.45 % and 50.71 % Fe at 1.62 tph, 2.22 tph and 2.68 tph respectively. The obtained upgrades are similar in the A Fraction for 30% and 35 % solid concentration across various feed rates, this suggest that the Fe grade is not sensitive to variation of the feed rate tested. The results furthermore suggest that at lower feed rates higher mass yield to concentrate can be expected

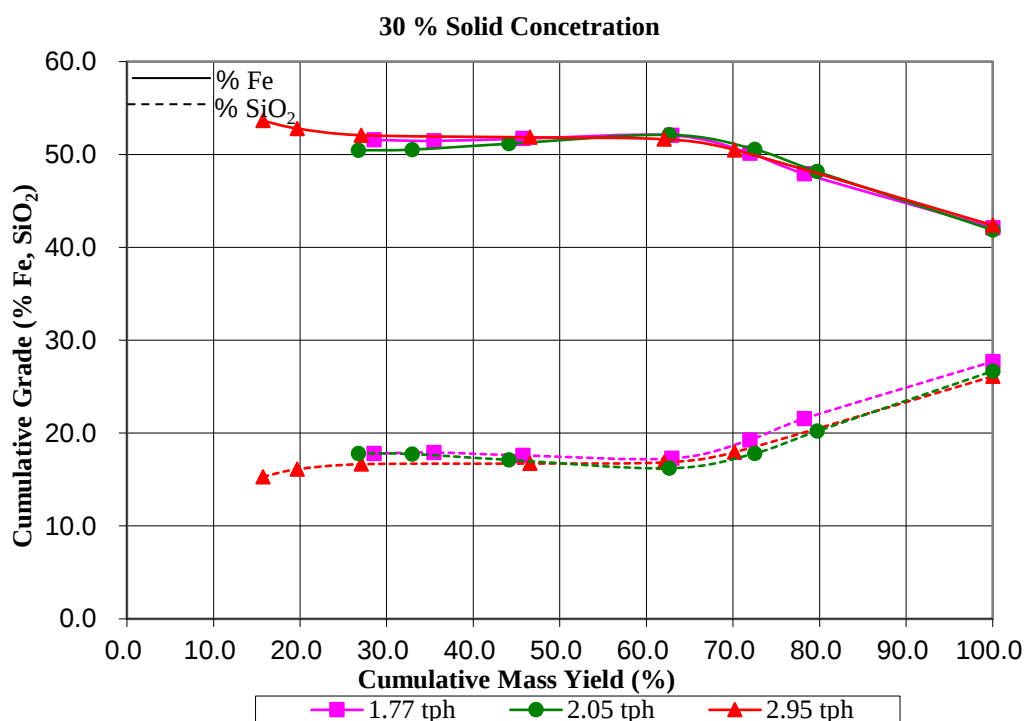


Figure 4 – Effect of feed rate on grade and yield at 30 % solid concentration

The corresponding SiO₂ grades at 30 % solid concentration were 17.74 %, 17.82 % and 14.30 % at 1.77 tph, 2.05 tph and 2.95 tph respectively, while The SiO₂ grades at 35 % solid concentration were 17.88 %, 17.80 % and 17.75 % at 1.62 tph, 2.22 tph and 2.68 tph respectively.

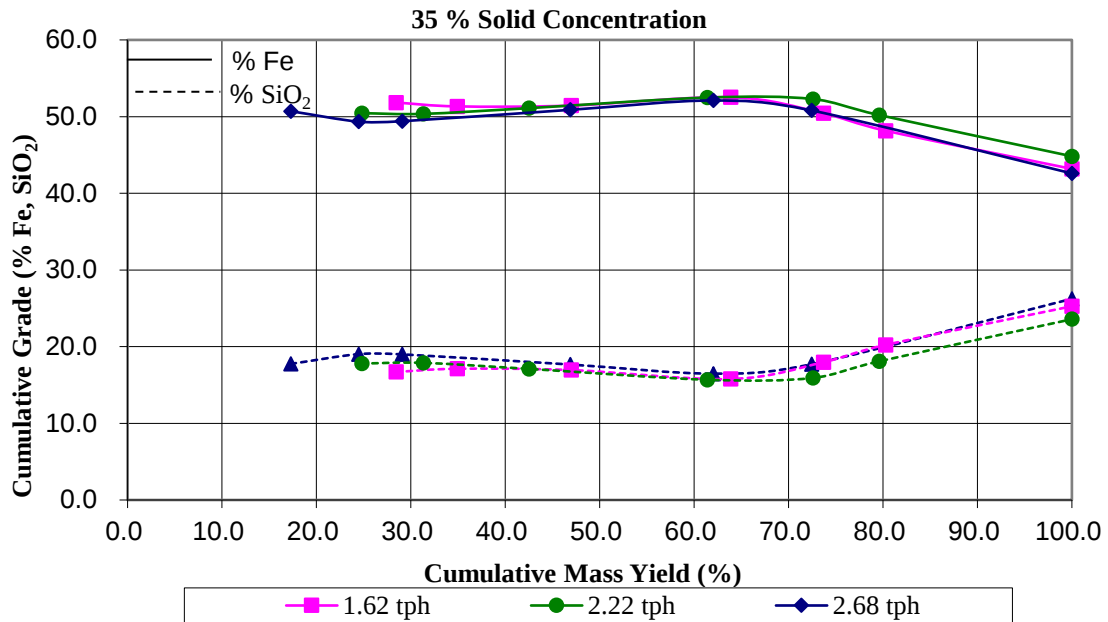


Figure 5 – Effect of feed rate on grade and yield at 35 % solid concentration

Figure 6 shows the effect of feed rate on grade and mass yield at 40 % solid concentration.

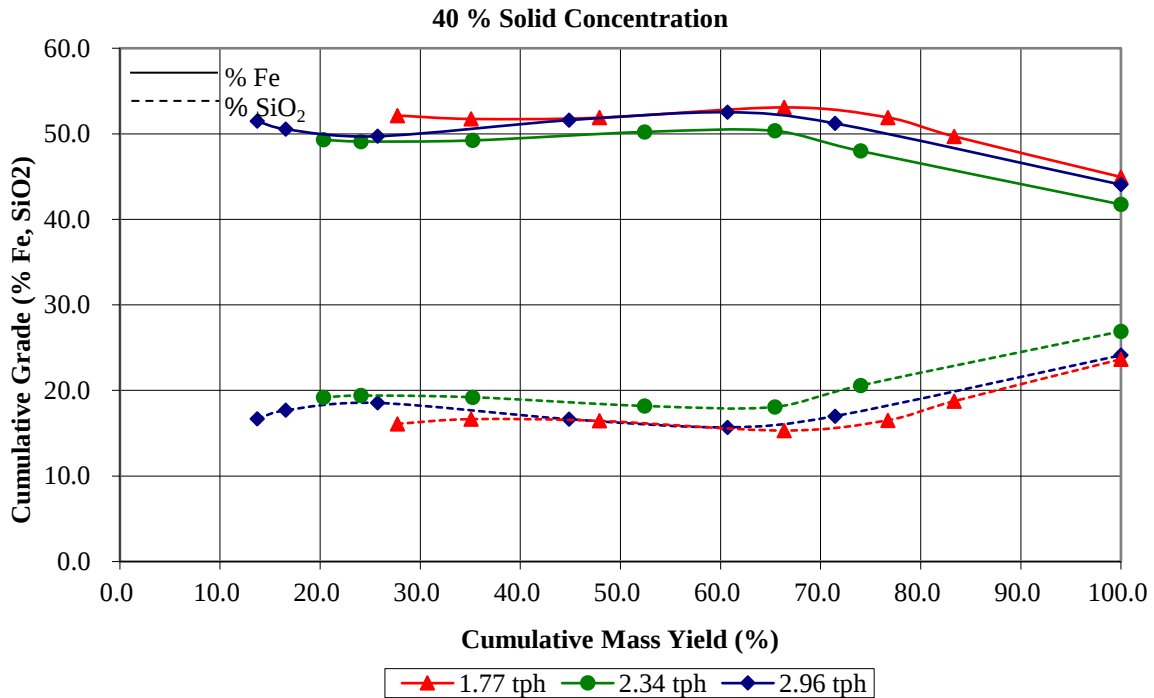


Figure 6 – Effect of feed rate on grade and yield at 40 % solid concentration

The highest upgrade achieved in the A Fraction was 52.14 %, 49.30 % and 51.48% Fe at 1.77 tph, 2.34 tph and 2.96 tph respectively. The obtained upgrades are similar to the 30% and 35% solid concentration across various feed rates ,this suggest that the Fe grade is not sensitive to variation of the

feed rate and solid concentration in this range. The results furthermore suggest that at lower feed rates higher mass yield to concentrate can be expected.

The corresponding SiO₂ grades at 40 % solid concentration were 16.10 %, 19.20 % and 16.70 % at 1.77 tph, 2.34 tph and 2.96 tph respectively.

Effect of Solid Concentration and Feed Rate on Recovery

Figure 7 shows the effect of feed rate and solid concentration on Fe recovery. Mouth organ product fractions A+B+C were considered as the concentrate for this interpretation.

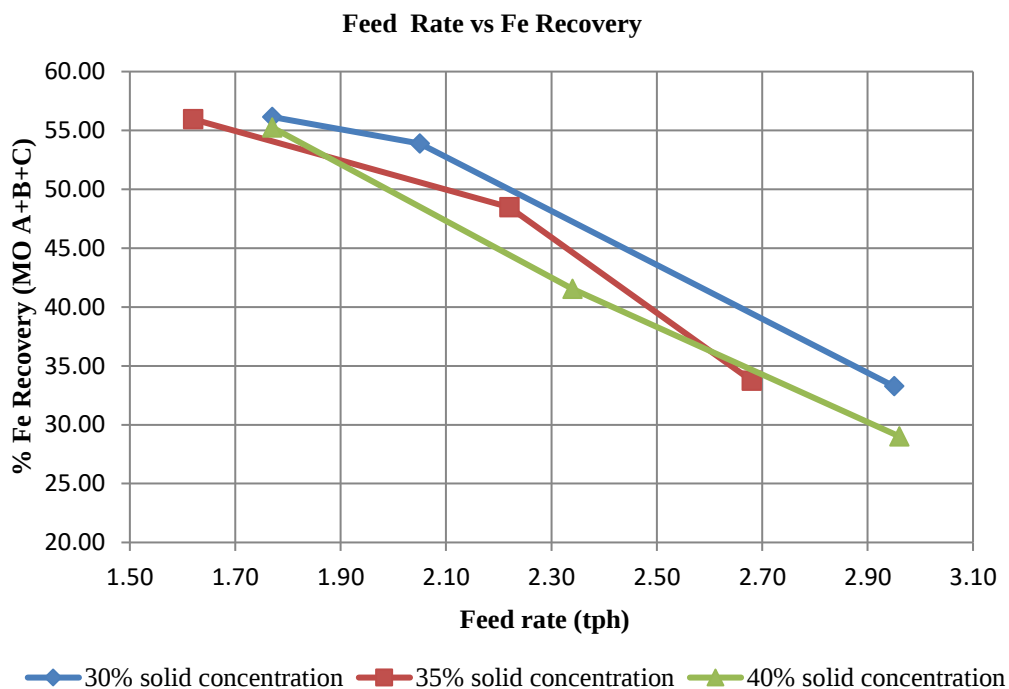


Figure 7 – The effect of feed rate and solid concentration on Fe Recovery

The results shows a linear relationship between the Fe recovery and the feed rate, with the highest recovery being at the lowest feed rate and decreases as the feed rate increases. The relationships also show that the highest Fe recoveries are achieved at the lower solid concentration and decreases as the solid concentration increases.

Effect of Wash Water on Grade

Figure 8 and Figure 9 shows the effect of wash water on grade at 30 % and 35 % solid concentration respectively. The highest Fe upgrade achieved in the A fraction at 30 % was 58.14 %, 59.37 % and 60.74 % Fe at 10 l/min, 16 l/min and 21 l/min wash water rate respectively. The highest Fe upgrade achieved in the A fraction at 35 % was 59.57 %, 59.57 % and 58.25 % Fe at 10 l/min, 16 l/min and 21 l/min wash water rate respectively. The Fe grade increase with an increase in wash water rate. The use of wash water improved the Fe grade by approximately 10%, this grade increase however came with a mass reduction of about 16 % in the A fraction of the MO compared to the test without wash water this shows the expected trade-off between grade and recovery when using wash water. The increase in wash water rate shows an increase in mass yield in the A fraction of the MO. This suggests that high wash water rate has an ability to divert a portion of the middling stream and channel it towards the concentrate stream.

The corresponding SiO₂ grades at 30 % solid concentration were 7.83 %, 9.15 % and 7.46 % at 10 l/min, 16 l/min and 21 l/min respectively, while the SiO₂ grades at 35 % solid concentration were 9.79 %, 8.71 % and 9.89 % at 10 l/min, 16 l/min and 21 l/min respectively.

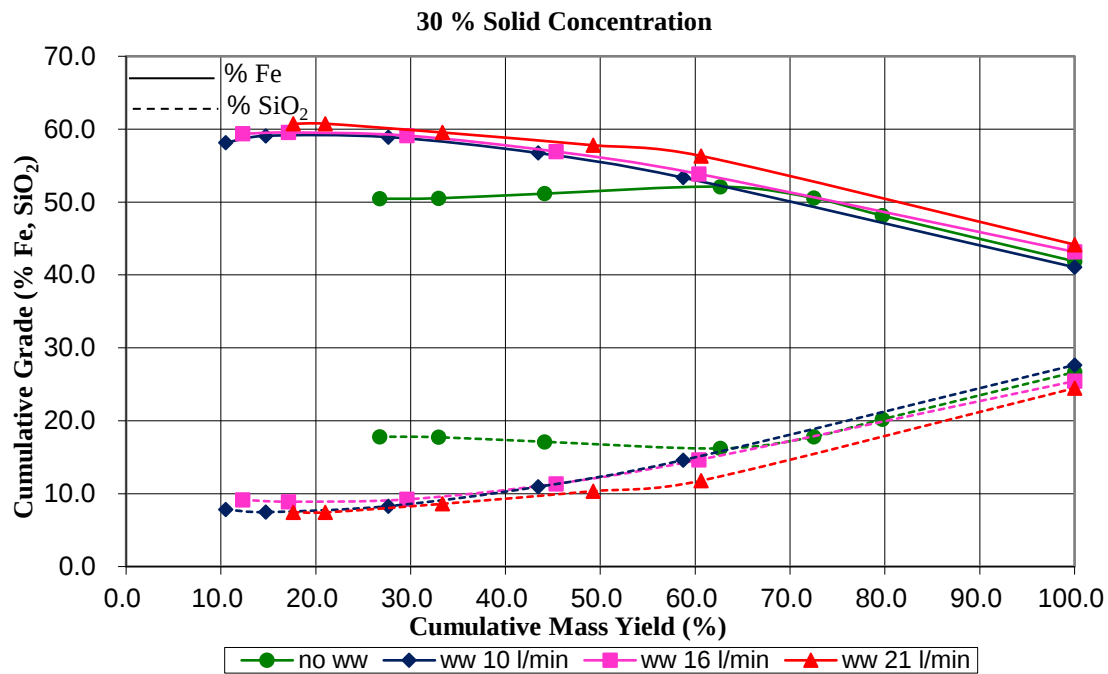


Figure 8 – Effect of solid concentration and wash water on grade and yield at 30 % solid concentration

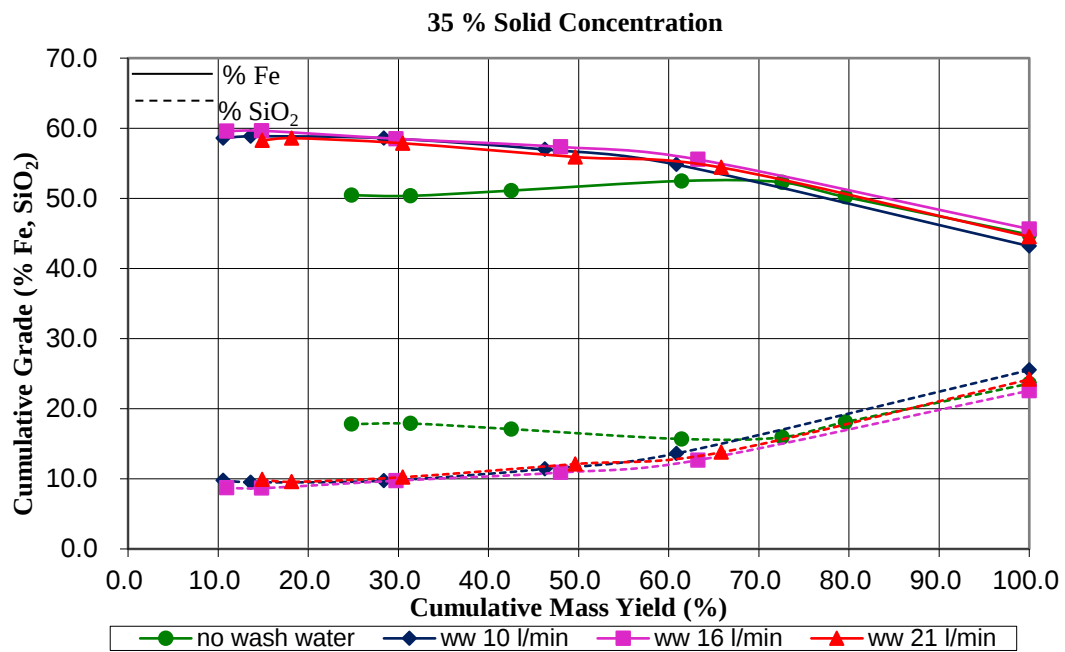


Figure 9 – Effect of solid concentration and wash water on grade and yield at 35 % solid concentration

Effect of Wash Water on Fe Recovery

Figure 10 shows the effect of wash water and solid concentration on Fe recovery. The Fe recovery increases with an increase in wash water rate at both 30 % and 35 % solid concentration. The Fe recovery decreases with an increase in solid concentration.

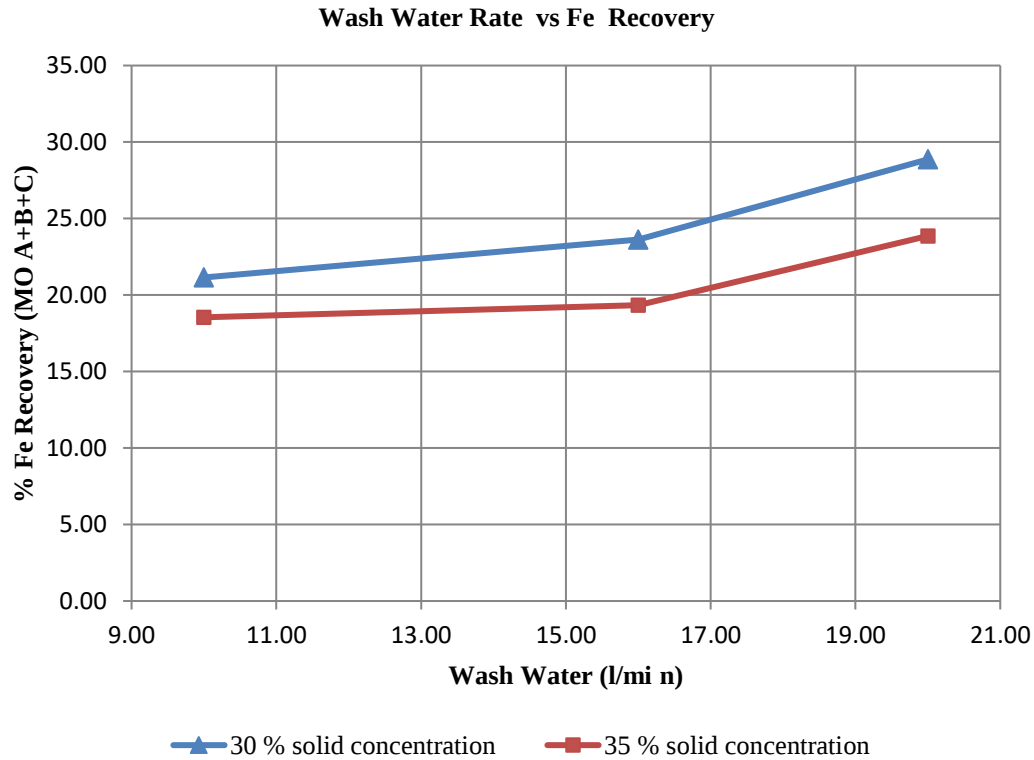


Figure 10 – The effect of wash water rate and solid concentration on Fe Recovery

As seen on Figure 8 and Figure 9, the increase in wash water rate shows an increase in mass yield as well as Fe grade in the concentrate fraction. A dual increase in mass and Fe grade therefore increases the Fe recovery. This suggests that high wash water rate has an ability to divert a portion of the middling stream and channel it towards the concentrate stream while simultaneously rejecting the gangue minerals. We are of the opinion that as the solid concentration increases the bed of particles in the middling becomes resistant to the wash water hence a decrease in recovery as solid concentration increases.

CONCLUSIONS

The Fe and SiO₂ grades in the concentrate (MO Fraction A) were found to be similar between 1.6 and 3 tph on the SC20HC/7 spiral. The results suggest that the concentrate grade is not sensitive to a variation in feed rate in the range of 1.6 to 3 tph on the SC20HC spiral. The results furthermore showed that the lower the feed rate, similar grades can be obtained at a slightly higher mass yield to concentrate than at higher feed rates. This phenomenon was observed at all solid concentrations, 30 %, 35 % and 40 %.

The relationship between feed rate and Fe recovery was shown to be linear as expected with the highest recovery being at the lowest feed rate and decreases as the feed rate increases. The relationship also showed that the highest Fe recoveries are achieved at the lower solid concentration and that the recovery decreases as the solid concentration increases.

The increase in wash water rate shows an increase in Fe grade as well as mass yield in the concentrate fraction. The Fe recovery increases with an increase in wash water rate at both 30 % and 35 % solid concentration. A dual increase in mass and Fe grade therefore increases the Fe recovery. This suggests that high wash water rate has an ability to divert a portion of the middling stream and channel it towards the concentrate stream while simultaneously rejecting the gangue minerals. The Fe recovery however decreases with an increase in solid concentration. We are of the opinion that as the solid concentration increases the bed of particles in the middling becomes resistant to the wash water hence a decrease in recovery as solid concentration increases.

It is well accepted that the use of wash water usually comes with a trade-off between grade and recovery. It is also worth noting that positioning of the wash water towards the middling against the flow on the spiral has a potential benefit to counteract the reduction in valuable minerals recovery as a result of using wash water. This positioning allows the material that has already separated to be collected undisturbed and rather assist with the fluidization of particles on the middling while simultaneously washing away gangue minerals.

RECOMMENDATIONS

The size effects were not investigated in this study. Particle size plays a huge role on separation on a spiral; future tests should therefore investigate the effect of wash water on the distribution of particle size across the spiral trough.

ACKNOWLEDGEMENTS

The authors are grateful to Anglo-American (Kumba Iron Ore Resources) for providing the ore for the experimental work and to Multotec Process Equipment for all the resources that enabled this work.

REFERENCES

- Atasoy, Y., and Spottiswood, D.J. (1995). A study of particle separation in a spiral concentrator. *Minerals Engineering*, Vol 8, No. 10, 1197-1208.
- Bazin, C., Sadeghi, M., Bourassa, M., Roy, P., Lavoie, F., Cataford, D., Rochefort, C., and Gosselin C.(2014). Size recovery curves of minerals in industrial spirals for processing iron oxide ores. *Minerals Engineering*, No. 65, 115-123.
- Boucher, D., Deng, Z., Leadbeater, T., Langlois, R., Renaud, M., and Waters K.E. (2014). PEPT studies of heavy particle flow within a spiral concentrator. *Minerals Engineering*, No. 62, 120-128.
- Holland-Batt, A.B. (2009). A method for the prediction of the primary flow on large diameter spiral troughs. *Minerals Engineering*, No. 22, 352-356.
- Holland-Batt, A. B. (1995). Some design considerations for spiral separators, *Minerals Engineering*, Vol.8, No. 1/2, 3-21.
- Holland –Batt, A. B. (1994). The dynamics of sluice and spiral separators, *Minerals Engineering*, Vol.8, No. 11, 1361-1390.
- Holland-Batt, A.B., and Holtham, P.N. (1991). Particle and fluid motion on spiral separators. *Minerals Engineering*, Vol 4, No. 3/4, 457-482.
- Holland-Batt, A. B. (1990). Interpretation of spirals and sluice tests, Institution of Mining and Metallurgy (Section C: Mineral Process .Extr. Metall), Vol 99, C11-20.
- Holtham, P.N. (1992). Particle transport in gravity concentrators and the Bagnold effect. *Minerals Engineering*, Vol 5, No. 2, 205-221.
- Holtham, P.N. (1990). Flow visualization of secondary currents on spiral separators. *Minerals Engineering*, Vol 3, No. 3/4, 279-286.
- Kapur, P. C., & Meloy T. P. (1998). Spirals observed, International Journal of Mineral Processing, Vol.53, 15-28.
- Richards, R. G., & Palmer M. K. (1997). High capacity gravity separators- A review of current status, *Minerals Engineering*, Vol.10, No.9, 973-982.
- Atasoy, Y., and Spottiswood, D.J. (1995). A study of particle separation in a spiral concentrator. *Minerals Engineering*, Vol. 8, No. 10, 1197-1208.
- Bazin, C., Sadeghi, M., Bourassa, M., Roy, P., Lavoie, F., Cataford, D., Rochefort, C., and Gosselin C.(2014). Size recovery curves of minerals in industrial spirals for processing iron oxide ores. *Minerals Engineering*, No. 65, 115-123.
- Boucher, D., Deng, Z., Leadbeater, T., Langlois, R., Renaud, M., and Waters K.E. (2014). PEPT studies of heavy particle flow within a spiral concentrator. *Minerals Engineering*, No. 62, 120-128.
- Holland-Batt, A.B. (2009). A method for the prediction of the primary flow on large diameter spiral troughs. *Minerals Engineering*, No. 22, 352-356.
- Holland-Batt, A.B., and Holtham, P.N. (1991). Particle and fluid motion on spiral separators. *Minerals Engineering*, Vol 4, No. 3/4, 457-482.

Holtham, P.N. (1990). Flow visualization of secondary currents on spiral separators. *Minerals Engineering*, Vol 3, No. 3/4, 279-286.

Holtham, P.N. (1992). Particle transport in gravity concentrators and the Bagnold effect. *Minerals Engineering*, Vol 5, No. 2, 205-221.

Hyma, D.B., and Meech, J.A. (1989). Preliminary tests to improve the iron recovery from the -212 micron fraction of new spiral feed at Quebec Cartier Mining Company. *Minerals Engineering*, Vol 2, No. 4, 481-488.

Pascoe, R.D., Power, M.R. and Simpson B. (2007). QEMSCAN analysis as a tool for improved understanding of gravity separator performance. *Minerals Engineering*, No. 20, 487-495.

Reddy, R., Kruger, L., Ramotsabi, C. M., & Lincoln, D. (2010). Iron ore beneficiation using the SC20HC spiral. *Proceedings of the Southern African Institute of Mining and Metallurgy Fines Beneficiation and de-watering and agglomeration* 13-29.

Sadeghi, M., Bazin, C. and Renaud M. (2014). Effect of wash water on the mineral size recovery curves in a spiral concentrator used for iron ore processing. *International Journal of Mineral Processing*, 129, 22-26.