The recovery of chrome and manganese alloy fines from slag

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For some time spirals have been the process equipment chosen to recover metal in the size range 0.15 to 3mm from ferrochrome and silico/ferro manganese slags. Recoveries of metal obtained using spirals are usually about 70 %. Spirals are also difficult to control.

By combining a novel gate on the Apic pneumatic fines jig with the recently developed Apic classifier, metal recoveries of 76 % and grades of over 90 % have been obtained for FeCr and SiMn slags in the size range 0.15 to 3 mm.

The paper compares classifier operating performance and costs with those spirals for FeCr and SiMn metal recovery from slags. The classifier technology can also be applied to chromite and iron ores and coal fines.

1. Introduction

Over the past two years Atoll (Apic Toll Treatment (Pty) Ltd) has explored various means, other than traditional spirals for the recovery of -1mm metal from slag. The search included process equipment like shaking tables, enhanced gravity separators and up current classifiers including the Yang jig (Packed bed pulsed column jig). With the help of Mintek several tests had been conducted on laboratory scale units (The results pointed to the use of an up-current classifier). To decide on the performance of the various process units, all factors had been considered, such as capital and operating cost, operability, flexibility, grade and recovery.

Atoll developed the Apic classifier from the test results and recommendations made by Mintek. The next challenge was to build an industrial scale unit that could deliver the same or better results than the laboratory scale Apic classifier. This was done at the Ferrochrome from slag recovery demonstration plant at Middelburg Ferrochrome and subsequently at the ferromanganese from slag recovery plant Canon, at Witbank. It was tied into the current system which did not contain an ultra fines (-1 mm) recovery circuit. The new classifier was able to produce very high grade ferromanganese at up to 5 tons per day metal recovered. As a result of the success of the Apic classifier at Canon a large classifier bank has been built for MARS (Metal Alloy Recovery Systems), Ferrochrome from slag recovery plant at Middelburg Ferrochrome.

2. Operation of the Apic classifier

The Apic classifier is similar to an elutriator, but its operation (separation on basis of size) differs significantly. An elutriator is used as a device for very sharp size cuts. These are achieved by using high upward water flows in a colum under free settling conditions. Smaller particles tend to settle at a slower rate than larger particles hence with an upward water flow larger particles will report to the bottom and smaller particles will be carried over the top. The Apic classifier uses lower water flows, which allows it to be a gravity separation device. Lower upward water velocities are used to increase the role of gravity in the separation device and hindered settling in the column causes the heavier particles to find their way to the bottom and lighter particles find their way up the column and over the top. The lower water velocity allows hindered settling to occur in the column which results in the segregation of particle based on their density. Therefore heavier particles settle to the bottom and lighter particles are squeezed upward to report to the overflow.

In the case of the ferromanganese recovery the product is the heavier material and will end up in the bottom of the classifier. Tailings will flow over the top. The whole process is automatically controlled. A set-point is keyed into the controller and if the process variable reaches the set-point, it discharges the product. If the product is not at the right grade, the set-point can be increased and if there is no feed or if there is a change in head grade, the controller will compensate for that.

3. Advantages of the Apic classifier

Classifiers have many advantages compared to other kinds of process equipment used for gravity separation. The benefits lie in capital and operating cost, operability, flexibility and recovery.

3.1. Capital cost

The capital cost of constructing an Apic classifier is less than that of constructing a full spirals plant. A full spirals plant, either has to have a lot of pumps, or it must have a very high structure to eliminate the cost of pumps. Apic classifiers don't need high structures or series of pumps. Other equipment such as shaking tables and enhanced gravity separators are too expensive to justify the recovery of ferromanganese from slag. The Apic classifier is cost effective when compared to other gravity separation equipment. A comparison of a recent cost for a spirals plant at Canon Engineering and the Apic classifier installed, showed that the classifier option was approximately 75% lower than that of the spirals circuit.

3.2. Operability

The operation of the Apic classifier is very easy and does not require any full time operators. The operation of spirals, require an operator to constantly check the spirals and to keep them clean from blockages and to make adjustments on the vanes if the head grade or feed tonnages change. The up-current classifier on the other hand requires very little attention. No full time operator is needed and it only needs small adjustments from time to time. By eliminating the need for a full time operator, operating costs are reduced.

3.3. Flexibility

The Apic classifier is much more flexible than spirals and can handle variations in feed grade and tonnages, because any change in the before mentioned parameters in spirals need adjustments to the vanes to maintain the desired product grade. The Apic classifier on the other hand copes with these changes automatically without any operator's interference. It can also cope with changes in feed material density, and can achieve a clean usable product in only one stage.

3.4. Recovery

Because of the hindered settling process, the Apic classifier recovers larger sized materials much more efficiently than spirals. The problem with spirals is that the 'coarser' particles end up in the middlings streams and are ultimately lost, while in the Apic classifier the 'coarser' particles are the easiest materials to recover. The grade that can be achieved in the Apic classifier is higher than that in a spirals plant. Grades of 99% clean product can be achieved in the classifier, but at the cost of recovery. Optimum product grade is approximately 90%, which allows high recovery and an acceptable product quality (Figure 1).

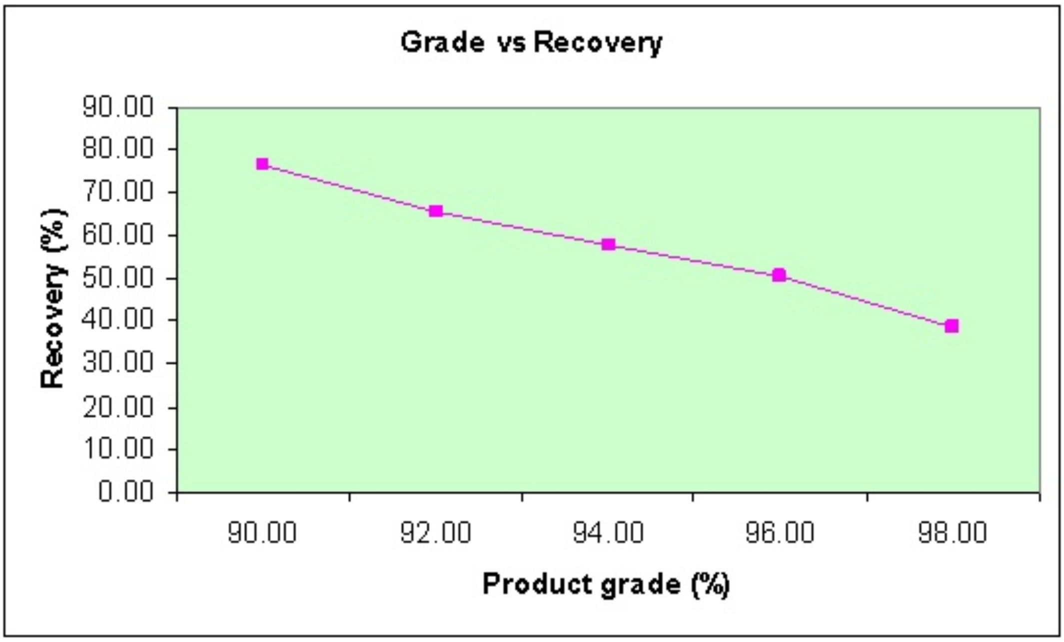

Figure 1. Grade vs Recovery graph for the recovery of ferrochrome from slag

4. Tests conducted by Mintek

The test done by Mintek was conducted on a laboratory scale unit with a capacity of approximately 300 kg/hr. A ferrochrome sample of -150μm has been tested in the Apic classifier and overall results revealed a product grade of 96.9% and a recovery of 89.1%. The results were further analyzed by testing grades and recoveries at different size fractions. Tests were conducted with spirals on the same material and only one stage was used for meaningful comparison.

. Results from Mintek tests

The results from Mintek tests done on the -150μm ferrochrome sample showed product grade in the underflow of 96.9% and a recovery of 89.1% (Table 1).

Table 1. Classifier results on -150μm ferrochrome slag

			Metal	
	Mass (g/min)	Mass (%)	Grade (%)	Recovery (%)
Overflow	304.5	50.0	11.8	10.9
Underflow	1006.7	50.0	96.9	89.1
Total	1311.2	100.0	108.7	100.0

The spiral test results from only one run can be seen in table 2 and the second run could be seen in table 3.

Table 2. Spiral results on -150μm ferrochrome slag – run 1

Sample	Mass (kg)	Mass %	Grade %	Metal Recoveries %
Conc	18.5	18.1	74.2	58.2
Tails	83.5	81.9	9.7	41.8
Feed	102.0	100.0	100.0	100.0

Table 3. Spiral results on -150μm ferrochrome slag – run 2

Sample	Mass (kg)	Mass %	Grade %	Metal Recoveries %
Conc	16.2	28.3	91.1	85.3
Tails	64.3	71.7	1.2	14.7
Feed	80.5	100.0		100.0

Table 4 and 5 shows the size distributions of the underflow (product) and the overflow (Tails) respectively.

Table 4. Size distribution of classifier underflow

Underflow Sizes (μm)	**Mass (g/min)**	**Mass (%)**	**Metal Grade (%)**	**Metal Recovery (%)**
+106	302.0	30.1	95.0	29.5
-106+75	446.0	44.4	97.0	44.5
-75+38	251.0	25.0	99.0	25.5
-38	5.0	0.5	99.0	0.5
Total	1004.0	100.0	390.0	100.0

Table 5. Size distribution of classifier overflow

Overflow Sizes (μm)	**Mass (g/min)**	**Mass (%)**	**Metal Grade (%)**	**Metal Recovery (%)**
+106	29.0	9.6	1.0	0.8

-106+75	120.0	39.7	9.0	30.3
-75+38	81.0	26.8	17.0	38.6
-38	72.0	23.9	15.0	30.3
Total	302.0	100.0	42.0	100.0

6. Apic classifiers' operations at MFC/ Canon/MARS

Atoll and Mintek started test work with a so-called Yang jig, or multi-cell jig in 2000. The first Yang jig pilot plant was installed at Middelburg Ferrochrome as part of a metal recovery plant system and was placed in production to determine the operability. During this period it was realized that the Yang jig without a pulse delivered even better results. The conclusion was that an up-current classifier should be used for recovery of micro fine metal from slag. As soon as the pilot plant was commissioned it took some time to get the classifier to produce a product that was according to the specifications of the client. The test work at the pilot plant at MFC was conducted to determine the optimum water flow and column density for the highest recovery of ferrochrome metal possible from the Apic classifier. The method to measure metal grade from slag in gravity separation was to look at liberated metal. To do this a modal analysis was employed by using the point counting method. The client needed 90% ferrochrome metal in the product, but the classifier could produce products of grades up to 99%.

Atoll's Canon Engineering plant at Transalloys, had two jigs installed in 1998. There were 2 fractions to be recovered from the dump in this plant. The coarse fraction was +6-25mm and the fine fraction was -6mm. It was discovered by various plant audits that the -1mm fraction exhibited a very low recovery, and that a lot of metal was lost in this fraction. The metal in that small fraction had to be recovered in order to increase the yield and to deliver a better service to Atoll's client. After some investigation into what should be used for the recovery of ultra fine metal, it was decided to use an up-current classifier instead of a spiral plant or any of the other gravity separation processes.

An industrial scale up-current classifier was installed at Canon Engineering, Transalloys at Witbank. The up-current classifier didn't perform as desired and after 6 weeks' trials it was replaced with a novel classifier of novel design, which was called the Apic classifier. It was a one stage classifier and was initially only used as a test unit. It was plugged into the system and was to be fed from a screen which dewatered the tailings from the fines jig. After a few trial and error attempts, the Apic classifier was able to recover extra metal of up to 5 tons per day from the fines jig tailings.

For the new metal recovery plant MARS (Metal Alloy Recovery Systems) at Middelburg ferrochrome it was decided to install the Apic classifier. This time experiments were conducted with a cluster of small classifiers, the same size as the pilot unit at MFC. The same results were achieved as with the previous Apic classifiers, but it proved to be a little more complex to control. A new unit, the same size as at Canon is to be installed at MARS and this unit will be part of a multi stage Apic classifier system.

7. Apic classifiers' results at MFC/Canon/ MARS

The results from the tests done at the MFC pilot plant for different column densities revealed that with an increase in bed density, the grade increases, but that the recovery decreases as show in table 6.

Table 6. Grade & Recovery from tests on FeCr at MFC

		Metal	
PLC setting (Density)	**Stream**	**Grade (%)**	**Recovery (%)**
2.60	Tails	19.00	34.37
	Product	95.00	65.63
2.65	Tails	22.00	41.62
	Product	96.00	58.38
2.70	Tails	25.00	49.48
	Product	97.00	50.52
2.75	Tails	29.00	61.11
	Product	98.00	38.51

The results from the tests at Canon varied little as head grade and feed tonnage changed. Spot tests for optimization revealed product grades varying between 90% and 97% with recoveries varying from 68% up to 85%. The recovery may not appear outstanding unless one takes into account that it is achieved through a single stage recovery device.

8. Conclusions and recommendations

The Apic classifier as a device to recover ferromanganese from slag is the most cost efficient piece of equipment. No restructuring of Canon Engineering was needed to accommodate the additional recovery of -1mm material. The existing operators only need to check the product occasionally while on their routine checks over the plant. It is not a high maintenance, high wear piece of equipment, and it can handle the head grade and feed change being fed into it. It also doesn't block up if there is a sudden density change in the feed, as the density inside the classifier stays constant. A change in the feed density will only result in a change in the density of the classifier overflow.

It would be advisable in future to try and implement more stages to the classifier system. If a rougher and cleaner is introduced, or a cleaner and scavenger is used the recoveries on the up-current classifier could be improved significantly.

Another option is to try and separate in two fractions below 1mm. The Mintek tests in table 4 and 5 revealed that different recoveries are achieved at different size fraction. The larger particles tend to have lower grades in the product, but higher recoveries than the smaller sized particles. The possible size fractions to be used would be -1mm+600μm and -600μm. The bottom size wouldn't be zero because desliming takes place earlier in the process. The bottom size would typically be 100μm. The easiest piece of equipment to do the cut for the two fractions below 1mm, would be an elutriator as it delivers a very sharp size cut. The elutriator cut size can also be easily changed by adjusting the water flow if the current size fractions do not deliver the desired recovery. These recommendations can aid in having a cost effective, reliable, flexible and high recovery ultra fines system.

Appendix A

Mintek test results: ferrochrome samples from up-current classifier tests

Table 1

-150μm feed

			Metal	
	Mass (g/min)	**Mass (%)**	**Grade (%)**	**Recovery (%)**
Overflow	304.5	50.0	11.8	10.9
Underflow	1006.7	50.0	96.9	89.1
Total	1311.2	100.0	108.7	100.0

Table 2

-150μm underflow

Underflow			**Metal**	

Sizes (μm)	Mass (g/min)	Mass (%)	Grade (%)	Recovery (%)
+106	302.0	30.1	95.0	29.5
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Table 3

-150μm overflow

Overflow			**Metal**	
Sizes (μm)	**Mass (g/min)**	**Mass (%)**	**Grade (%)**	**Recovery (%)**
+106	29.0	9.6	1.0	0.8
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Total	302.0	100.0	42.0	100.0

Table 4

-150μm spiral feed run 1

Sample	Mass (kg)	Mass %	Grade %	Metal Recoveries %
Conc	18.5	18.1	74.2	58.2
Tails	83.5	81.9	9.7	41.8
Feed	102.0	100.0		100.0

Table 5

-150μm spiral feed run 2

Sample	Mass (kg)	Mass %	Grade %	Metal Recoveries %
Conc	16.2	28.3	91.1	85.3
Tails	64.3	71.7	1.2	14.7

Feed	80.5	100.0	100.0

Appendix B

Middelburg pilot plant results: -1mm ferrochrome samples

Table 6: Density setting 2.60

	Mass (t/hr)	Mass (%)	Grade (%)	Recovery (%)
Feed	0.59	100.00	40.00	100.00
Overflow	0.40	67.50	14.00	23.62
Underflow	0.19	32.50	94.00	76.38

Table 7: Density setting 2.65

	Mass (t/hr)	Mass (%)	Grade (%)	Recovery (%)
Feed	0.69	100.00	40.00	100.00
Overflow	0.50	72.37	19.00	34.37
Underflow	0.19	27.63	95.00	65.63

Table 8: Density setting 2.70

	Mass (t/hr)	Mass (%)	Grade (%)	Recovery (%)
Feed	0.70	100.00	40.00	100.00
Overflow	0.53	75.68	22.00	41.62
Underflow	0.17	24.32	96.00	58.38

Table 9: Density setting 2.75

	Mass (t/hr)	Mass (%)	Grade (%)	Recovery (%)
Feed	0.77	100.00	40.00	100.00
Overflow	0.61	79.17	25.00	49.48
Underflow	0.16	20.83	97.00	50.52

Table 10: Density setting 2.80

	Mass (t/hr)	Mass (%)	Grade (%)	Recovery (%)
Feed	0.87	100.00	40.00	99.61
Overflow	0.73	84.28	29.00	61.11
Underflow	0.14	15.72	98.00	38.51