Increasing the flotation recovery of <10 µm PGE with magnetic conditioning – A plant evaluation

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Improving the selective flotation recovery of the valuable but difficult-to-recover <10 µm minerals is a challenge faced by all flotation operations. Despite the improvements in many areas of mineral processing this challenge remains. Magnetic conditioning to selectively aggregate <10 µm minerals, to increase their momentum; their resulting collision efficiency and ultimately their flotation recovery has been successful in base metal flotation. However, for PGE flotation, magnetic conditioning hasn't been extensively tested. This paper describes an evaluation of magnetic conditioning at Anglo American Platinum's Mogalakwena Complex that demonstrates a 0.97% increase in Pt recovery to high confidence. The plant test is combined with a detailed mineralogical evaluation to discern what PGE minerals and what size fraction's flotation recovery increases with magnetic conditioning. The mineralogical analysis shows that it is the Pt alloys and ferro platinum in the <10 µm fraction whose recovery increases most significantly.

Keywords: Mogalakwena, platinum, flotation, PGE, mineralogy, magnetic conditioning

INTRODUCTION

Anglo American Platinum, operates the Mogalakwena open pit mine and processing plant in the Limpopo province of the Republic of South Africa. It is Anglo American Platinum's largest platinum producing concentrator. Mogalakwena is also a large palladium producer as well as producing other platinum group elements (PGE) like gold and rhodium. Anglo-Platinum's 2020 annual report records that in 2020, Mogalakwena produced 501,000 ounces of platinum, 565,000 ounces of palladium and 136,000 ounces of other platinum group elements (1).

Mogalakwena Mineralogy and Grind Characteristics

The Mogalakwena orebody is part of the South African, Bushveld Igneous Complex that comprises four limbs. The Northern Limb of the Bushveld Igneous Complex contains the Platreef deposit and Mogalakwena mines the northern part of the Platreef deposit. Mogalakwena Complex is located approximately 35 km to the north of the town of Mokopane.

The Platreef PGE ore is more diverse and complex than the two other major South African PGE ore types; the Merensky reef and the UG2 ore. Moreover, relative to these two ores, the Platreef ore has a much greater variance in the rock types within the deposit. Rock types of the Platreef ore are generally pyroxenites, serpentinites and calc-silicates.

The Mogalakwena deposit has low concentrations of Ni, Fe and Cu sulphides. The primary base metal sulphides are pyrrhotite, pentlandite and chalcopyrite, though there are lesser amounts of other Fe, Ni and Cu sulphides. Ni and Cu content in the ore averages about 0.2% and 0.1% respectively, relatively low for a base metal sulphide flotation operation. The pyrrhotite concentration is higher than both the pentlandite and the chalcopyrite, but varies throughout the ore. Unlike, UG2 ore, chromites are not in high concentrations and their rejection is not a focus of the operation. The overwhelming value in the ore is the PGE, particularly the Pt and the Pd.

PGE deportment is of two main mineral types. About 45% of the PGE occur as either discrete PGE minerals, mainly tellurides, sulphides, arsenides or alloys; particularly PGE-ferro alloys. The remaining PGE are in solid solution in the base metal sulphides. At Mogalakwena, it is primarily the palladium that is in solid solution in the base metal sulphides and mainly in the Ni sulphides. Platinum occurrence in solid solution in the sulphides is much less significant than for palladium. Generally, the palladium and platinum in the ore is comparable in grade and each in the 1-2 ppm range, while the concentration of other PGE is much lower.

The average grain size of the PGE in the Mogalakwena deposit is about 90 µm, but the PGE losses at Mogalakwena are primarily in the <25µm fraction, with about 55% of the PGE in the tail reporting to the <25 µm fraction. Moreover, the extreme fineness of the PGE results in about 36% of the total PGE losses being in the <10 µm fraction. As expected the <10 µm PGE are overwhelmingly liberated. The <10 µm size class is known to be difficult to recover through conventional flotation mechanisms due to their low probability of collision with the bubbles and low momentum. The mineralogy and sizing of the PGE losses will be discussed in more detail in the results section, where detailed mineralogy of the tail has been undertaken.

Mogalakwena Flotation Circuit

The Mogalakwena flowsheet is a standard PGE flowsheet, with a primary milling circuit followed by a primary rougher flotation circuit. The rougher tail reports to a secondary milling circuit, that has a ball mill and an Isamill in series with the discharge reporting to the scavenger flotation circuit and the scavenger tail being final tail. Upgrading of the rougher and scavenger concentrates occurs in two stages of cleaning with the cleaner scavenger tails reporting back to the scavenger feed. At Mogalakwena there are two equal, parallel rougher and scavenger lines, with total throughput averaging above 25,000 tpd. Rougher and scavenger concentrates are combined to feed two parallel cleaning lines with the tail feeding the cleaner scavenger banks. Overall metallurgical results are good with PGE recovery in the high 70s and about 20 times upgrading to the final concentrate.

There is 24-hour automatic sampling of the feed, final tail and the filter concentrate with detailed assaying of the critical elements.

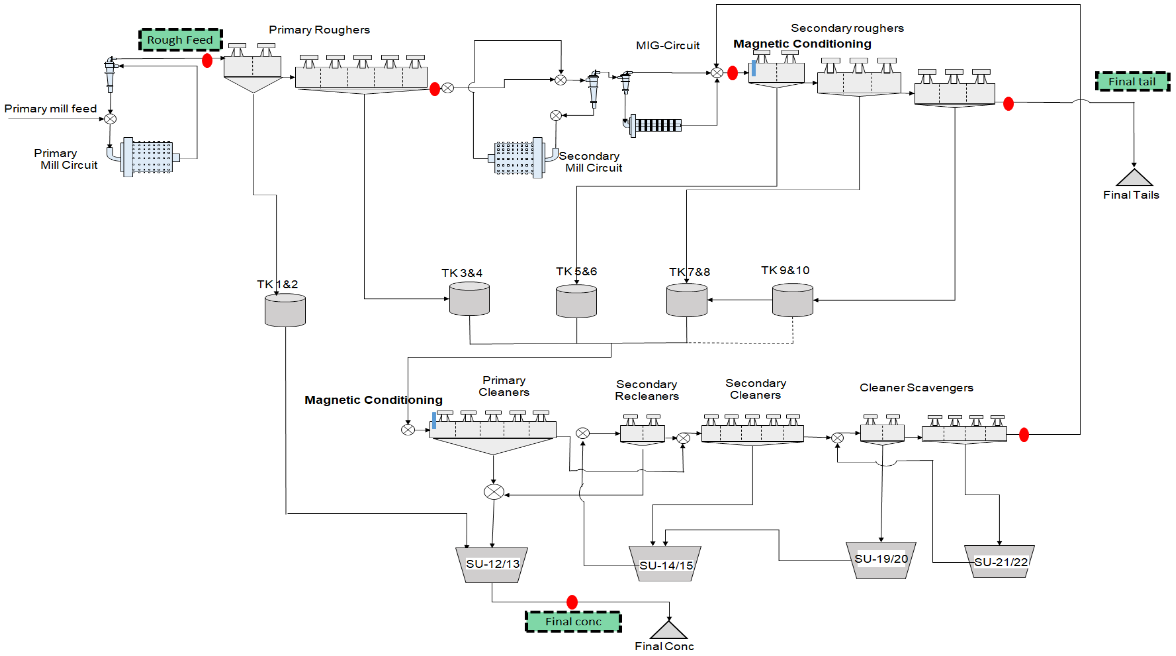

Figure 1. Mogalakwena circuit.

Fine Sulfide Mineral Recovery
The recovery of <38 µm, and more particularly <20 µm or even < 10 µm sulphide minerals by flotation is an ongoing challenge for flotation plant operators; the same size recovery challenge applies to PGE flotation as well. Selectively improving the recovery of the <10 µm PGE is the problem this work sought to attack. Mogalakwena's final grind size is fine (tail about 50% <25 µm) and the PGE, Ni and Cu losses are >50% in the <25 µm fraction. It has been shown by Duan *et al.,* (2) and others, that in base metal sulphide flotation the cause of poor fine mineral flotation is the low momentum of the fine particles, limiting their collision efficiency with the bubbles in the slurry. Fine minerals, because of their low momentum remain in the flowstream and slide around the bubble, rather than colliding with the bubble. Most methods that have been developed to increase the fine mineral recovery are based on reducing the bubble size, or increasing the particle momentum (mass or velocity). All these methods have their limitations either by decreasing selectivity (3, 4), being detrimental to the flotation of coarser particles (increasing particle-bubble detachment) (3, 4) or being expensive with long conditioning times and expensive reagent consumption (5). Split flotation, another method proposed, where fine minerals are floated in a separate plant, under unique fine mineral conditions, is also expensive because a second, parallel float plant is required to be built (6).

Magnetic Susceptibility of PGE minerals
The paramagnetic susceptibility of common minerals that are recovered by flotation like chalcopyrite, bornite and pentlandite is well documented in the literature (7). However, the magnetic susceptibility of PGE minerals is not reported in the literature, probably because isolating sufficient pure PGE minerals to measure their magnetic susceptibility is difficult, and expensive. Native Pt and Pd are slightly paramagnetic, whereas Au is diamagnetic. However, as expected PGE-Fe alloys have been shown indirectly to be strongly paramagnetic. Rosenblum *et al., (*8) found that platinum – iron alloys had a range of strong paramagnetic susceptibilities depending on the Fe content of the alloys, which varies. However, the platinum-iron alloys were recovered in the magnetic concentrate. Ferron and Davison (9) also found that platinum-palladium-iron alloys were strongly paramagnetic and that high recoveries, at reasonable concentrate grades could be achieved by magnetic separation, from a tailings sample.

The Mogalakwena final concentrate's magnetic susceptibility was measured in 2019 and 2020, using a AGICO MFK1-A kappabridge magnetometer. It was found that the concentrate samples were strongly paramagnetic, greater than chalcopyrite, a paramagnetic mineral that has shown increase in flotation recovery after magnetic conditioning (11). The results are shown in Table A.

Table A. Magnetic susceptibility measurements for Mogalakwena concentrates and literature value for chalcopyrite

SAMPLE	Magnetic Susceptibility x 10^{-9} m^3kg^{-1}
Mogalakwena Concentrate (2019)	2130
Mogalakwena Concentrate (North Pit) Feb 2020	2690
Chalcopyrite Literature (Svoboda 1980)	1596

Of course, this concentrate is not pure PGE minerals, but contains sulphides and gangue. However, since a large proportion of the PGE metals are in solid solution in the sulphides, it indicated that the recovery of the <10 µm PGE may respond to magnetic aggregation.

Other reports in the literature have shown that minor inclusion of impurities in sulphide minerals can change diamagnetic minerals to paramagnetic minerals. The effect of iron substitution in sphalerite is well documented (7) and more recently paramagnetic galena has been reported, due to iron in solid solution in the galena mineral (10). More recent, as yet unpublished research, by Hudbay Minerals and Ausmetec, has shown that molybdenite with either iron or rhenium impurities is also paramagnetic.

Magnetic Aggregation to Increase Fine Mineral Recovery

Many published plant studies have shown that magnetic conditioning, using high strength, high gradient, rare earth, permanent magnets to selectively aggregate the fine paramagnetic minerals will increase the flotation recovery of these fine paramagnetic minerals. The selective magnetic aggregation increases fine particle momentum by increasing their mass, thereby increasing bubble collision. The key is that the magnetic aggregation is selective for the paramagnetic minerals that float. Magnetic conditioning typically occurs either immediately prior to flotation, or in the initial flotation stage. Many plant studies have been published showing a selective increase in fine mineral recovery, with some referenced here (10, 11, 12, and 13). These studies have been predominantly focussed on the paramagnetic sulphides, though Rivett *et al.*, (11) showed an increase in the recovery of the fine PGE, Au, with magnetic conditioning. Churchill's (14) plant testwork showed a large increase in < 38 µm PGE plant recovery at the same mass pull with magnetic conditioning on UG2 ore. While this plant study was on a cleaner circuit, it also demonstrated that magnetic conditioning will increase PGE recovery but that this is dependent on the mineralogy.

EXPERIMENTAL

Trial Methodology

A plant trial of magnetic conditioning was carried out at Anglo American's Mogalakwena PGE mine from November 2019. Considering that 50% of the PGE were <25um in the final tail, the objective of the plant trial was to measure an improvement in plant PGE recovery with magnetic conditioning from the incumbent operation. A total of fourteen high strength, high gradient, rare earth magnetic conditioning units were installed and commissioned in both lines of the scavenger cell as well as the primary cleaner cell to increase the recovery of fine liberated PGE. The feed to the scavenger circuit is a combination of the tertiary milling circuit product and the cleaner scavenger tail hence the fine particle size distribution of the stream. This feed stream has a large proportion of less than 25um particles and therefore installing the magnetic condition units at the head of the scavenger circuit was identified as a better alternative compared to installing it ahead of the rougher flotation circuit where there is a lower abundance of <25um particles. Similarly, magnetic conditioning units were installed in the primary cleaner cell to reduce recirculation of fine PGE via the cleaner scavenger tail back to the scavenger circuit. After a safe and successful installation and commissioning of the technology, a sequential two-day 'ON' two-day

‘OFF’ trial campaign ran for a period of nine months. The magnetic conditioning technology uses a pneumatic control system designed to automatically lift each magnet in and out of the slurry. When the magnetic conditioning technology was in the ON state, the rare earth magnet inside a rubber lined stainless steel tube cycled in the slurry for five minutes and out of the slurry for one minute. It was important for the magnet to cycle out of the slurry for approximately one minute in the ON position to prevent ferromagnetic build-up from occurring which in turn allowed for efficient operation of the technology. During the OFF position, each magnet was lifted out of the slurry for the entire two-day duration.

Assay Analysis

Representative samples comprising samples collected at intervals of 15 minutes, and composited over a 24-hour period for the key streams (feed and tailings) were collected. The samples were collected using the automated metal accounting samplers. The concentrate sample was not taken because the only representative final concentrate sample was collected after the filtration process. This was not a suitable sample for a daily test because of the delay time from flotation to filtration and the mixing of concentrates in the concentrate thickeners. The daily composite samples were prepared and sent for assay analysis to enable the calculation of the PGE recovery, and hence determine whether there was a positive effect in PGE metallurgy recovery with magnetic conditioning.

PGE Recovery Analysis

The PGE recovery for the different trial conditions was calculated using the feed and tailings assay results. The recommended statistical method used for comparing the PGE recovery for the two test positions ON (magnet cycling in and out for cleaning) and OFF (magnet out of the slurry) is the paired t-test whereby adjoining periods of ON and OFF were compared as a pair. Napier Munn (15) considers the paired t-test to be the most powerful statistical method for tests with an ON and OFF state in mineral processing plants.

Mineralogical Analysis

Final tailings samples from the automatic tailings samples for the ON and OFF conditions for the entire test period was collected and composited for mineralogical analysis. The samples were sized into three fractions; < 10 µm, 10-25 µm and >25 µm. The three fractions were assayed and polished sections of each fraction were analysed using two types of instruments namely quantitative electron microscopy (QEMSCAN) and mineral liberation analyser (MLA) to test the hypothesis on reduction of losses in the < 10 µm micron size fraction when the magnets were ON. This was also done to determine the difference in the mineral speciation of the tailings for the two trial conditions in order to understand which mineral species were impacted by the agglomeration process. A second mineralogical analysis was undertaken to look at the mineralogy of the strongly paramagnetic/ferromagnetic minerals in the final tail and cleaner tail stream. This was a spot grab sample, where a rare earth magnet was lowered into the pump box for a short period and the mineral that attached to the magnet was sent for mineralogical analysis.

RESULTS AND DISCUSSION

PGE Results – Plant Data

A total of 48 pairs were analysed after elimination of the outliers using the Grubbs test (18). The paired ‘t’ test was used to calculate the mean for the two test conditions ON and OFF and then the level of statistical confidence for the difference between the two means was calculated. This was conducted to establish whether the difference was real, or just the result of random variability in the plant.

In order to ensure that any changes in metallurgical performance could only be attributed to the magnetic conditioning On-Off condition, a comparison of the input parameters was conducted and is presented in Table B. A two-tailed paired ‘t’ test was used to compare the input parameters.

Table B. Comparison of factors affecting recovery, average values for the test period

	Concentrate Mass pull (%)	Flotation Feed Grind (%-53µm)	Plant Feed grade (g/t)
Magnet On	4.24	66.80	3.46
Magnet Off	4.19	65.72	3.43
Difference	0.05	1.08	0.03
Confidence (%)	75.05	59.04	68.77

Mass pull is a controllable variable in the process and is normally controlled within strict limits; therefore, it was not expected that a significant difference in mass pull would be observed. This was demonstrated in the results which indicated an absolute difference of only 0.05% with low confidence (75%). It can therefore be concluded that any changes in the metallurgical performance did not occur as a result of a change in the mass pull.

Liberation also contributes to the flotation performance. Grind was used as a proxy for liberation, and the results show that the percentage of material in the-53µm fraction was comparable between the ON and OFF condition (1.08% absolute difference at 59% confidence). Therefore, liberation could also be ruled out as a contributor the changes in the metallurgical performance. The third factor affecting flotation performance that was considered is the flotation feed grade. The feed grade had an insignificant difference of 0.03g/t at a confidence level of 68.8% between the two conditions. With the results showing insignificant differences in mass pull, grind and head grade it was concluded that the ON-OFF experimental design was successful in ensuring that the input parameters for the two trial conditions were the same. The test for outliers covered the plant instabilities, only data rejected on the basis of the test for outliers was excluded. A comparison between the plant recoveries was then conducted with regards to 4T, platinum (Pt), palladium (Pd) as well as base metals (Cu and Ni) are shown in table C. A one-tailed paired 't' test was undertaken because the outcome to be tested was whether magnetic conditioning increases flotation performance. There is no theoretical or metallurgical evidence that magnetic conditioning would reduce the flotation performance, hence a two-tailed test is not applicable.

Table C. Average plant recovery comparison between the two conditions

Plant Recovery (%)	4T PGE	Pt	Pd	Cu	Ni
Difference (On-Off)	0.64	0.97	0.44	0.29	-0.76
Confidence (%)	87.38	94.45	77.82	73.88	80.7

The paired t-test indicated a 0.64 % increase in the overall PGM recovery with magnetic conditioning applied, with a confidence of 87%. Pt recovery increased by 0.97% at 94.45% confidence, and Pd recovery increased by 0.44% with 78% confidence. In terms of the base metals, the Cu recovery increased by 0.29% with the lowest confidence at 74%. The recovery impact on Ni was negative, however there is low confidence in the differences (81%).

PGE Results – Mineralogical Results

Mineralogy Comparison of ON and OFF Final Tail

The mineralogical results are not a statistical comparison because there is a single tails composite sample for ON and a single tails sample for OFF. Rather it is a quantitative and qualitative investigation of the difference in mineralogical composition of the final tails, to determine which minerals are impacted by the magnetic conditioning. Only samples corresponding to the 48 pairs that were analysed after eliminating outliers were composited for mineralogical analysis. Because only final tails samples were investigated the analyses assumes that the feed for the two conditions were the same. This is a reasonable assumption for a daily ON/OFF test over a period of nine months, and is consistent with the statistical plant test feed data, that showed no difference between the two conditions. Generally, the mineralogical results are consistent with the plant results but give insight into the plant results. The assays and size by size assays for the magnetic conditioning ON are in Table D and OFF are reported in Table E.

Table D. ON tails composite chemical assay

Size µm	% Mass	Pt ppm	Pd ppm	Au ppm	Cu ppm	Ni ppm	%Cr_2O_3	%S
-10	16.5	0.33	0.55	0.17[1]	230	1030	0.39	0.25
+10-25	35.9	0.21	0.23	0.05	101	593	0.45	0.26
-25 Combined	52.4	0.25	0.33	0.09	142	731	0.43	0.26
+25	47.6	0.25	0.27	0.07	209	608	0.36	0.13
Head	100.0	0.25	0.30	0.08	174	672	0.40	0.20

[1] Au assay may be elevated due to nugget effect

Table E. OFF tails composite chemical assay

Size µm	% Mass	Pt ppm	Pd ppm	Au ppm	Cu ppm	Ni ppm	%Cr_2O_3	%S
-10	20.6	0.37	0.53	0.04	182	921	0.41	0.24
+10-25	24.0	0.20	0.20	0.06	92	531	0.48	0.22
-25 Combined	44.6	0.28	0.35	0.05	134	711	0.45	0.23
+25	55.4	0.27	0.30	0.08	210	562	0.34	0.12
Head	100.0	0.27	0.32	0.07	176	629	0.39	0.17

The reduction in Pt assay in tail with the magnetic conditioning in the <10 µm is 10.8% while in the <25 µm size fractions its 10.7%. The reduction in the total Pt assay was 7.4%. It is clear from the Pt assays that the magnetic conditioning substantially reduced the Pt reporting to tailings in the fine fractions; this is consistent with a selective aggregation of fine Pt particles. It is very interesting that the effect is so substantial for the <10 µm fraction, which is notoriously difficult to recover. These results are consistent with the plant test results. Similarly, for Pd there was a 7% reduction in the total Pd assay in the tail, and a 6% reduction in the Pd assay in the <25 µm fraction. The <10 µm Pd assay was however slightly higher for the ON condition. These results are consistent with the plant testwork that showed that the magnetic conditioning had a greater impact on Pt than on Pd. The Au results for the ON condition in the <10 µm size fraction appears to be marred by the nugget effect. If the Au in this fraction was comparable to the OFF assay then there would have been a similar reduction in the Au in the composite final tails. The Cu and Cr_2O_3 are similar for the ON and OFF conditions, but the Ni and S are higher with the ON condition.

Mineralogical analysis of the PGE in the <10 µm fraction reveals that the magnetic conditioning is significantly reducing the Pt alloys and ferro platinum in the tail. The results for the <10 µm size fraction PGE distribution by mineral for the ON and OFF conditions are reported in Table F. The distribution of PGE in the Pt alloys and ferro-platinum in the <10 µm size fraction is reduced by around 80% with magnetic conditioning, which is a substantial reduction. This is the major mineralogical impact of magnetic conditioning, and is consistent with the study by Rosenblum (10) that showed that Pt associated with the alloys, particularly the ferro-alloys had a strong positive magnetic susceptibility. The large reduction in the PGE distribution in the Pt alloys and ferro-platinum increases the relative PGE distribution in the other <10 µm minerals. Nevertheless, because the assay data and plant test showed an overall reduction in the PGE in the tail with magnetic conditioning, an increase in PGE distribution in the non-Pt alloy/ferro-platinum minerals only means that the absolute amount is similar between the ON and OFF conditions, and the reduction is predominantly in the Pt alloy/ferro-platinum minerals.

Table F. Distribution of PGE by mineral species in the <10 fraction of plant tails

PGE Species	Magnetic Conditioning ON	Magnetic Conditioning OFF
Pt-sulphide	10	5
PtPd-sulphide	3	1
PtRh-sulphide	-	1
Pt-telluride	23	23
Pd-telluride	26	9
Pt-arsenide	22	12
Pd-arsenide	-	-
Ferro-platinum	2	11
Pt-alloys	2	18
Pd-alloys	3	3
PGE-sulpharsenides	3	3
Gold	5	13
Total	100	100
No of Particles	111	115

The mineralogical analysis of the base metal sulphides (BMS) identified that they are composed of pyrrhotite, pentlandite chalcopyrite and some pyrite, but approximately 80% of the BMS in tails is pyrrhotite. In the <10 µm fraction with magnetic conditioning there was a reduction in the distribution of liberated pentlandite and pyrrhotite in the tail and a slight increase in the liberated chalcopyrite. Pentlandite, pyrrhotite and chalcopyrite are paramagnetic. There is also a reduction in the <10 µm BMS tail fraction with magnetic conditioning, supporting the conclusion that there is an increase in BMS recovery with magnetic conditioning. Increasing BMS recovery would be expected to increase PGE recovery. Moreover, unlike a sulphide float where selectivity against iron sulphides is important to maintain concentrate grade, for Mogalakwena selectivity against BMS is detrimental due to the relatively low BMS in the feed and PGE associated with the BMS.

Mineralogy of a Tail Magnetic Grab Sample

A rare earth magnet was lowered into the final tailings pump box, where it remained for a short period before being retrieved and the material that attached to the magnet was sent to the mineralogical laboratory for analysis. This was conducted to validate the presence of paramagnetic species in the tailings stream and to confirm the results obtained during the plant trial. While both a cleaner tail and a final tail sample was collected in this way, the results and discussion will focus on the final tail sample because it relates most closely to the mineralogy of the tailings samples from the ON and OFF trial. The chemical analysis is given in Table G.

Table G. Chemical analysis of magnetic grab sample from the plant tails

Size µm	% Mass	Pt ppm	Pd ppm	Au ppm	Cu ppm	Ni ppm	%Cr_2O_3	%S
-10	6.0	0.82	0.99	0.16	367	2650	2.00	8.18
+10-25	21.9	0.98	1.00	0.14	258	3240	2.21	13.70
+25	72.1	2.19	1.80	0.33	816	3080	1.37	7.23
Head	100.0	1.84	1.58	0.28	667	3089	1.59	8.70

What is immediately striking is the upgrading in the magnetic fraction, relative to the total tail. Assuming that the total tail has an assay similar to the average of the ON and OFF tail, then for the PGE there is a 4-7 times upgrade, and for the base metals and Cr_2O_3there is a 4-5 times upgrade with magnetic conditioning. Relative to the total tail, the magnetic fraction is rich in the valuable elements. For the S there is a >40 times upgrade suggesting that the pyrrhotite is strongly concentrated by the magnetic extraction. Mineralogy does indeed show that about 21% of the sample is BMS, and that the BMS is 95% pyrrhotite, compared to 0.5% of the ON/OFF tail sample being BMS, of which about 80% is pyrrhotite. The >40 times upgrade of pyrrhotite in the magnetic fraction corresponds to the >40 times upgrade of the S in the magnetic fraction. It is not surprising that the distribution of the coarse fraction is much higher in the grab sample than the total tail, because this is a magnetic separation sample and magnetic separation is not very efficient on very fine fractions. Liberation analysis shows that most of the PGE in the magnetic fraction are not liberated, unlike the ON and OFF tail samples where they were liberated. More than 80% of the PGE are associated with BMS silicates and oxides. No doubt this is due to the preferential removal of coarse mineral by the magnet and the association of the PGE with the pyrrhotite. The concentration of PGE in the magnetic fraction and the mineralogical analysis of the magnetic fraction does show that the PGE minerals at Mogalakwena have a strong, positive magnetic susceptibility, either as unique PGE minerals or because of their association with minerals in the slurry that have a positive magnetic susceptibility. This suggests that the PGE-containing minerals would aggregate if magnetised and as a result float with higher efficiency in the same way that paramagnetic chalcopyrite or pentlandite does. This, in addition to the ON-OFF tail mineralogy, is another confirmation of the plant trial results. Previous test work on the cleaner tail demonstrated that wet high intensity magnetic separation (WHIMS) will concentrate the PGE in the magnetic fraction (17), confirming the positive magnetic susceptibility of the PGEs. However, the recovery of PGE at a high upgrade is relatively low. This is partly due to the PGE grain size being primarily <25 µm, where magnetic separation has limitations, and partly due to poor selectivity against gangue with positive magnetic susceptibility. Magnetic separation cannot exploit the positive magnetic susceptibility of the PGEs to improve their recovery at acceptable concentrate grade, but magnetic conditioning - because it is not a separation process - does improve recovery by exploiting the positive magnetic susceptibility of the PGEs. These 'magnetic fishing' results have another application. In determining whether a mineral will respond to magnetic conditioning the magnetic susceptibility of the concentrate is measured to see if it is paramagnetic. This is a good approach where the concentrate is overwhelmingly the mineral to be measured. However, for PGE or precious metal flotation the key minerals are in very low concentration. Maybe 'magnetic fishing' – magnetic concentrating or upgrading – is a better method to determine whether the valuable minerals of interest have a strong positive magnetic susceptibility.

CONCLUSION

The magnetic aggregation trial using magnetic conditioning units was a success at Mogalakwena Concentrators in selectively improving PGE recovery. Daily plant metallurgical data showed an improvement in metallurgical performance was achieved at plant scale. Average Pt recovery showed the highest improvement of 0.97% at 94.45% confidence. The mineralogical investigation showed that the change can be attributed to magnetic aggregation of the <10 µm Pt. This Pt would not have been recovered without magnetic aggregation, due to their low momentum and low probability of collision. All other recovery inputs were comparable for the two trial conditions. Magnetic conditioning is clearly impacting the difficult-to-recover <10 µm PGE: a welcome result. The mineralogical analysis of the tailings samples for the two trial conditions also show that magnetic conditioning produces a reduction in the ferro-Pt and Pt alloys in the final tail. These Pt minerals have been shown by others (8 and 9) to be paramagnetic, confirming the magnetic aggregation mechanism. Furthermore, the analysis of the magnetic component of the tailings grab sample indicates that the PGM containing minerals are magnetic and would aggregate if magnetised, thereby resulting in increased probability of recovery. This deduction also supports the aforementioned conclusions.

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Mgciniwethu Khumalo

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Mgciniwethu Khumalo is a seasoned Metallurgist who has worked in the PGM concentrating environment for more than 9yrs. He started his career in the Eastern Limb where he spent 4yrs at a UG2 ore concentrator plant before moving to a plant that treats Platreef ore in the Northern Limb where he is leading the team responsible for metallurgical performance at Anglo American Platinum’s biggest concentrator.

Mgciniwethu is passionate about process optimization and has conducted and guided numerous value add projects in the value-based ore characterization, comminution, reagent screening, flotation, water quality and real time sensing fields. He also provides support to the Data Analytics and Digital Transformation team as a subject matter expert. One of his achievements has been the study which informed the conversion of the circuit configuration at Mogalakwena Concentrator in a bid to improve the recovery of base metals by minimizing overgrinding.