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A comparison of different cyclones in addressing challenges in the classification of the dual density UG2 platinum ore

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It is common practice in the mineral processing industry to use hydrocyclones for particle classification. However, classification in the UG2 platinum circuits using the hydrocyclone poses major challenges due to the differences in density between silica and chromite, the two major components of this ore. Silica,-the PGM carrying component, has an average density of 2.7 and the barren chromite component has an average density of 4.5.

When conventional and flat bottom cyclone are used there is a misplacement of particles due to differences in density leading to inefficiencies in the classification by size. As a result of the density effect, coarse silica reports to the overflow, resulting in loss of recovery, and fine chromite reports to the underflow, resulting in loss of milling capacity and unnecessary production of fine chromite. A classifier based on a different concept was required in the classification of UG2 platinum ore.

The three-product cyclone, which is a hydrocyclone with two concentric vortex finders to produce three distinct products, has been tested in the UG2 ore application and indications are that misplacement of particles due to differences in the component densities can be minimized through the use of this unit. Industrial and pilot plant trials were conducted and indications are that the three-product cyclone can be installed to selectively produce a middlings stream that can be screened using Pansep screens to provide a screen oversize, which is predominantly coarse silica that can be preferentially reground to recover the PGM values contained in the coarse silica.

Introduction

In minerals, processing, if milling is accepted as a key cost factor and flotation as the key efficiency factor[1], then classification being the link between these two important process aspects is a critical step in determining the overall concentrator performance. If the classification stage is not efficient, both the grinding and flotation processes cannot be optimized or operated efficiently.

The basic function of classification units in closed circuit grinding operations is to remove fine material from the grinding circuit and feed it to the flotation circuit, and to re-circulate the coarse material to the mill for further grinding. If the classification circuit is achieving its intended functions, only the material that meets the size requirements for the flotation circuit escapes the grinding circuit and the coarser particles are recirculated to the grinding mill for further reduction in size. In the ideal case, all the material that has met the size requirements for the flotation circuit must be removed from the grinding circuit. Optimum operations in the classification circuit ensures that only particles in the size range that maximizes recovery report to the flotation.

Among the available commercial classifiers presented by Mills[2], hydrocyclones have been shown to be the most widely used classifiers in the target size range of 10 to 100 μm where the recovery of the platinum group metals (PGMs) from the UG2 using the flotation process is maximized. Other common classifiers such as screens have been shown to be preferred in the size ranges above 500 μm, which is much higher than the preferred cut size. Even though screens can be used to classify particles at a cut size of 200 μm, it is difficult to operate screens with apertures in the region below 600 μm efficiently when large quantities of material are being processed. Due to the constraints of the size requirement for the flotation of the UG2 ore, the hydrocyclone has rendered itself the preferred classifier. However, classification of the UG2 platinum ore using conventional hydrocyclones is a major challenge due to the differences in the component densities of silica,-the PGM carrying component, and chromite, the barren component[3,4].

Conventional hydrocyclones classify feed materials into two products, the overflow and underflow streams. The main features and operations of conventional hydrocyclones have been discussed by many authors[5–7]. However, in the UG2 ore the differences in the component densities have given rise to inefficiencies in the component split to the cyclone overflow and underflow streams of the conventional hydrocyclone. This results in high re-circulating loads of fine dense materials and the coarse particles of silica, the light component, reporting to the flotation circuit when they are not suitable for floating.

In an effort to improve the classification efficiencies, longer vortex finders terminating deep down in the cylindrical section of the hydrocyclone have been installed in most of the cyclones, as opposed to the common practice in the base metal industry of using vortex finders that terminate well above the junction between the conical and cylindrical section (Figure 1). In some cases, hydrocyclones with large cone angles, termed flat bottom cyclones, have

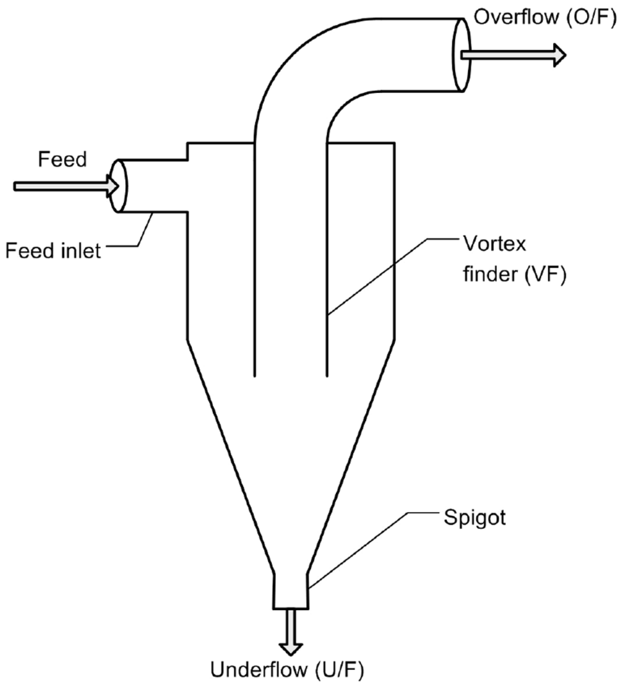

Figure 1. Schematic showing the main parts of the conventional hydrocyclone

been installed. The flat bottom cyclone is basically a conventional hydrocyclone with a long cylindrical section and a completely flat bowl-shaped bottom[8] as shown in Figure 2. The concept in the flat bottom cyclones is to promote density separation, while maintaining a good size separation.

Despite all these changes in the design parameters of the hydrocyclone, the problems caused by the differences in the component densities of the UG2 platinum ore have not been resolved. From the work that was conducted under the AMIRA P9L project[9], it was realized that the new type of hydrocyclone, termed the three-product cyclone, can provide a solution to the dual density problems in the classification of the UG2 ore. Trials on a new type of cyclone with two concentric vortex finders, termed the three-product cyclone, have been conducted.

The three-product cyclone is a modification of the conventional cyclone with an additional vortex finder inserted concentric to the existing vortex finder to provide a second overflow stream[10]. A schematic of the three-product cyclone is given in Figure 3. To distinguish between the two vortex finders, the conventional vortex finder is termed the outer vortex finder (OVF) and the additional vortex finder termed the inner vortex finder (IVF). The concept of the three-product cyclone developed from the need to produce three unique products from the feed stream using one classifier unit. The three-product cyclone gives a fines product stream from one overflow stream and a middlings product stream from the other, and a coarse product stream from the underflow[4]. The product from the inner vortex finder is termed the inner overflow (OFI) and the product from the annulus (gap between the inner and outer vortex finder) is called the outer overflow (OFO). The underflow is discharged through the spigot.

Exeperimental work

Experiments were conducted using a 600 mm diameter cyclone on the custom-built rig at Eastern Platinum Limited, a Lonmin platinum concentrator treating UG2 ore. The test rig was operated in closed circuit with a Weg variable speed pump located at the secondary mill discharge sump of the production circuit. Volumetric flow rate measurements from the feed and overflow streams were obtained using the large tanks on the test rig fitted with ATS actuators and Ajax level sensors. Custom-made automatic sample cutters were installed for taking representative samples[3].

The performance of the conventional, flat bottomed, and three-product cyclones was compared by conducting tests under similar conditions using the same test rig. All the test

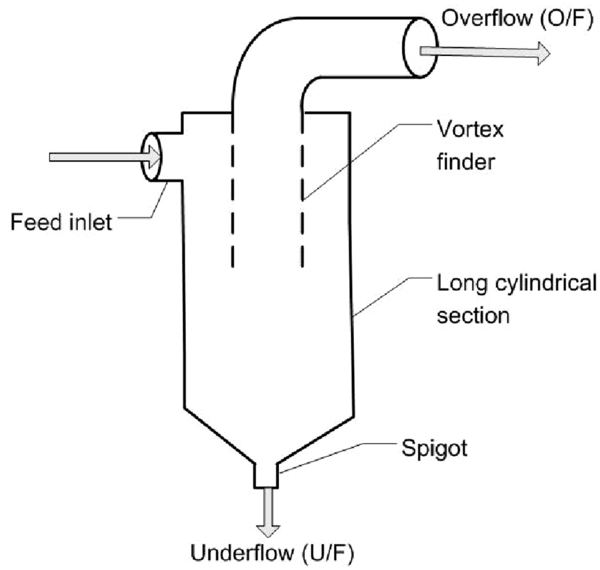

Figure 2. Schematic showing the main parts of the flatbottomed cyclone

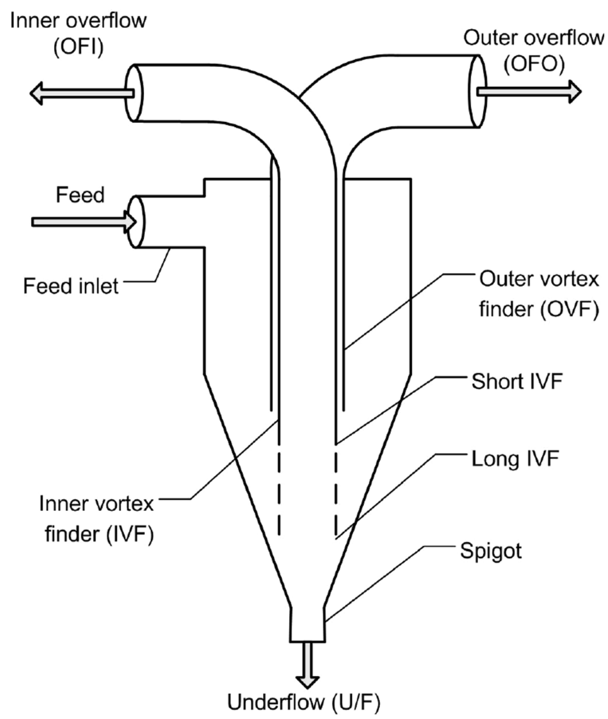

Figure 3. Schematic showing the main parts of the three-product cyclone

samples were prepared and processed using the standard procedures. The size fractions from the screening process were sent for assays to analyse for silica and chromite and, in some cases, the platinum group elements.

Results and discussion

Several experiments were performed to test the concept of the three-product cyclone in the UG2 platinum ore application. In addition, experiments were conducted using the conventional and flat bottom cyclone. Efficiency curves were used to represent the performance of the conventional and flat bottom cyclone[7,11–13].

Comparison of the conventional and flat bottom cyclones

Efficiency curves for both the conventional and flat bottom cyclone obtained using stream particle size and mass flow rate data, are given in Figure 4. A correction to remove the effect of the bypass was made for each efficiency curve. A correction for the bypass fraction was made to the actual efficiency curve to enable reasonable equipment comparisons to be made[13]. From Figure 4, it appears that the flat bottom cyclone gives a coarser cut size (d_{50}) and the overall recovery curve is flatter than that of the conventional cyclone of the same size. The actual d_{50} value for the flat bottom cyclone was 140 µm while that for the conventional cyclone was 73 µm; the corrected d_{50c} values were 81 µm and 160 µm respectively. This is in conformity with what was reported by Schmidt and Turner[8]. Since the function of the conical section in the hydrocyclone is to direct the centrifuged solids towards the central axis of the cyclone and to give rise to a concentration of solids at the spigot opening, large included cone angles result in a coarse cut size and reduced recirculating loads. The efficiency curves show that the flat bottom cyclone has a small fraction of fines in the underflow stream compared to the conventional cyclone. The reduction in the by-pass of fines to the underflow in the flat bottom cyclone leads to an improvement in the quality of the recirculating load.

Since the actual and corrected efficiency curves obtained from stream particle size and mass flow rate data do not take into account any effects of particle characteristics, such as density, which have been shown to have an influence on the classification process, separate efficiency curves for silica and chromite recovery to the underflow of the convention and flat bottom cyclone were determined, Figure 5 and Figure 6. Efficiency curves for silica and chromite were used as a basis for comparing the cyclone performance in terms of the recovery of the components to the underflow stream.

The component efficiency curves suggest that the mechanisms of separating the low- and high-density components are very different between the conventional and flat bottom cyclones. Although the displacement of the d_{50} value for chromite from that of silica for the conventional cyclone fell in the same range as for the flat bottom cyclone, the conventional cyclone was shown to cut more finely for both components. The d_{50} values for the conventional hydrocyclone for silica and chromite components were 90 µm and 73 µm, respectively, while those for the flat bottom cyclone were 160 µm, and 110 µm. After correcting for the by-pass fraction, the corrected cut size (d_{50c}) values were 108 µm for silica and 80 µm for the chromite component for the conventional hydrocyclone, and 210 µm and 170 µm for the flat bottom cyclone.

The component efficiency curves have shown that the efficiencies in the recovery of silica and chromite from the flat bottom cyclone were fairly close at coarser sizes and then drifted apart as the curve approached finer sizes. This is different from the conventional cyclone where the component recovery curves were closer at coarser sizes and drifted apart in the middle section after which they became close before criss-crossing at 60 µm. It can be seen that the silica component curve is flatter than the chromite curve for the conventional cyclone, indicating that the cyclone is not effective in recovering silica to the underflow stream.

Comparison of the d_{50} values from the conventional cyclone has shown that chromite had a lower d_{50} than silica, indicating that a large quantity of chromite reports to the underflow at a particle size where it is expected to be ejected from the grinding circuit. As a result, the mill loses capacity for fresh feed and a lot of energy is used up grinding the already fine chromite. The discussion has shown that in multi-component ores where the densities of the major components are large, stream particle size and flow rate data is inadequate to accurately quantify the performance of the cyclones in the circuit. Size by size assays, analysing for the major ore components such as

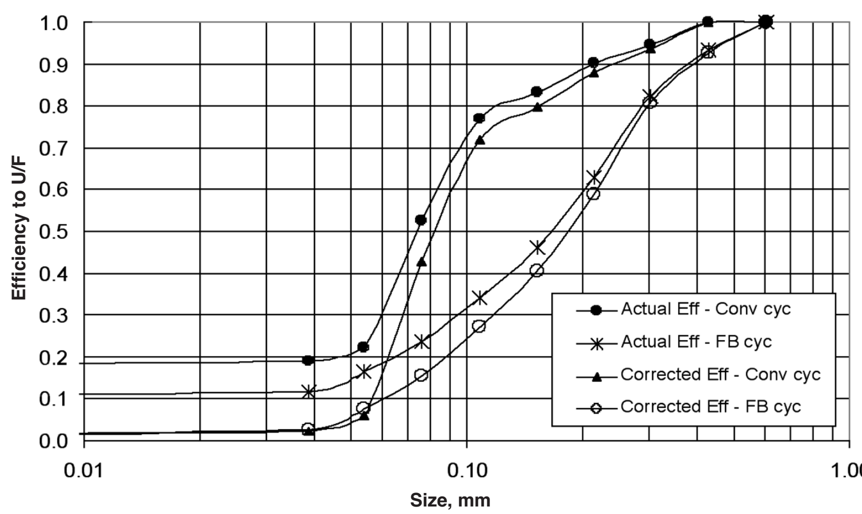

Figure 4. The actual and corrected efficiency curves for the conventional and flat bottom cyclones

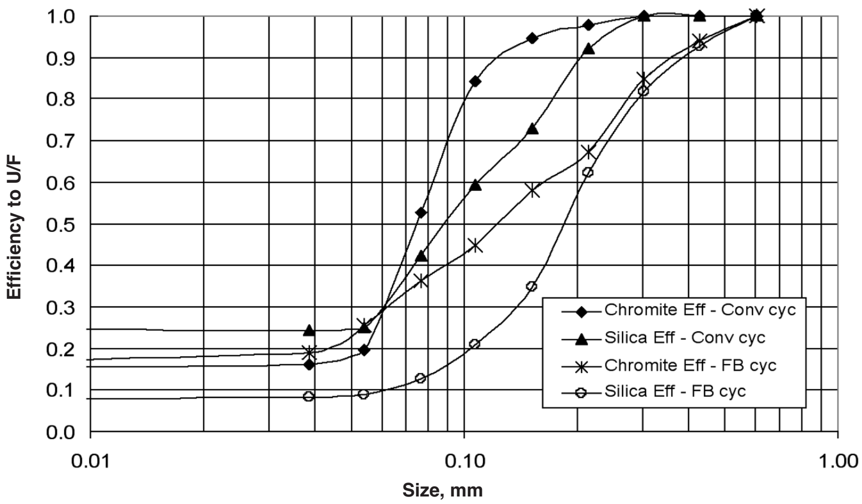

Figure 5. Actual efficiency curves for conventional and flat bottom cyclones for silica and chromite

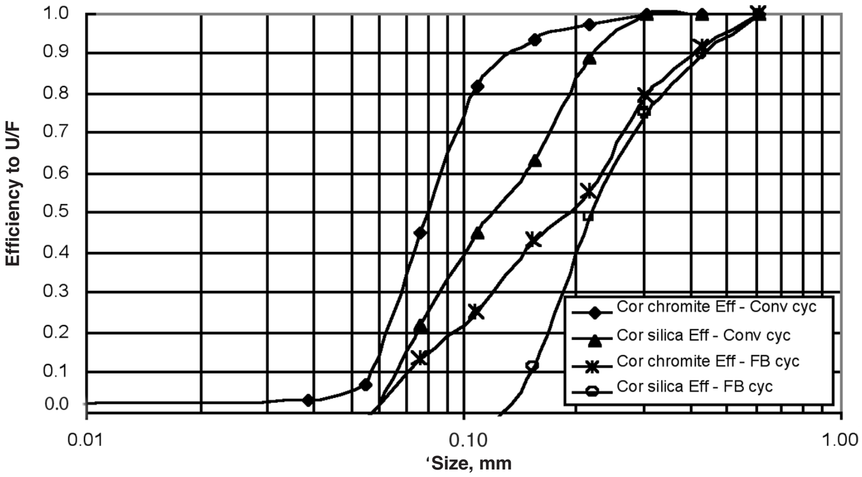

Figure 6. Corrected efficiency curves for conventional and flat bottom cyclones for silica and chromite

silica, and chromite are required in quantifying the performance of cyclones in the UG2 circuits. Particle size and component data have shown that the conventional and flatbottom cyclones do not yield the desired classification results.

The three-product cyclone

Several tests were conducted using the 600 mm three product cyclone and only a sub-section of the results have been presented here. Figure 7 shows the split ratios of the feed to the product streams from the testwork conducted using the industrial scale conventional, flat bottom, and three-product cyclones. It can be seen that the conventional cyclone has a high split ratio of 0.6 reporting to the underflow compared to the flat bottom cyclone, which has a split ratio of 0.3 reporting to the underflow. The three-product cyclone was shown to give split ratios of 0.3, 0.2, and 0.5 to the finer overflow stream, middlings stream, and underflow stream, respectively. It should be noted that specifying the split to the underflow in the three-product cyclone is inadequate due to the presence of a third product stream, which is absent in the conventional and flat bottom cyclones. In the application of the three-product cyclone the split ratio to the middlings product is critical in a sense that it determines the effectiveness of the circuit where the cyclone is installed. In the application where the three-product cyclone is used to produce a finer overflow that goes to the flotation circuit, an underflow that is re-circulated to the mill for further grinding, and the middlings stream that is fed to the fine screens to further remove the particles in the intermediate size ranges, it is desirable to have a split ratio in the range 0.15 to 0.20 reporting to the middlings product of the cyclone. It has been shown by Mainza and Powell that suitable split ratios in the three-product cyclone can be obtained by using the correct combination of the inner and outer vortex finder diameters as measured by the Selection Area Ratio (SAR)[3]. The use of smaller spigot sizes than generally required in the conventional cyclone were recommended.

In applications involving classification of ores containing different density components, the split by component is critical in assessing the performance of the classification unit being used. Figure 8 shows the silica component split ratios for the conventional, flat bottom, and three-product cyclones. Examination of the silica splits suggest that when a conventional cyclone is used, 40% of the silica reports to

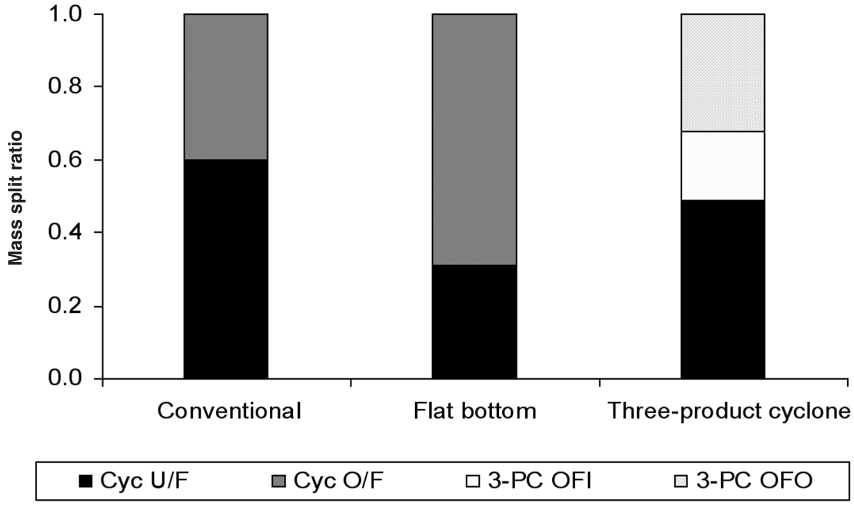

Figure 7. Mass splits to the respective cyclone products

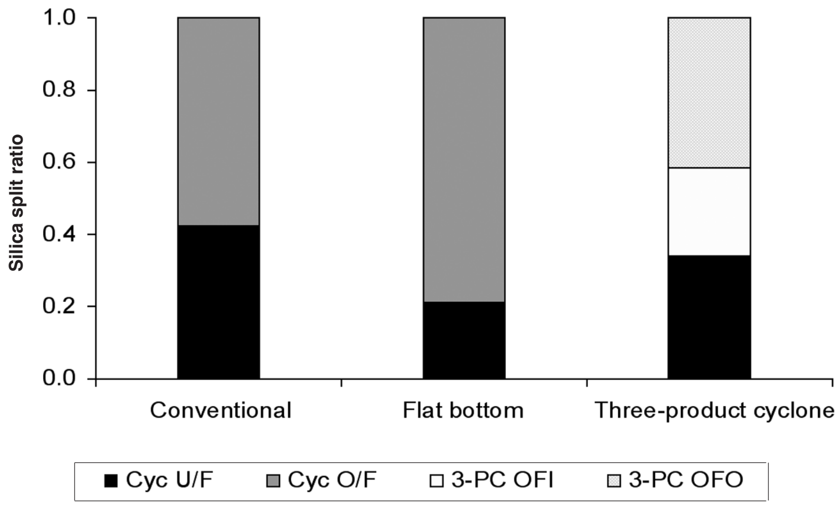

Figure 8. Average silica splits to the respective cyclone product streams

the underflow while only 20% reports to the underflow of the flat bottom cyclone. The silica split in the three-product cyclone is 25% to OFI, 40% to OFO, and 35% to the underflow. The high amount of silica in the OFO, in this case the middlings product, is attractive for the application of the three-product cyclone to provide a stream for fine screening to recover the PGM values contained in the intermediate size range.

The split ratios of the chromite component are given in Figure 9. From the total chromite in the feed stream, 70% reported to the cyclone underflow when the conventional cyclone was used while 40% reported to the underflow of the flat bottom cyclone. In the three-product cyclone, the chromite component split was 18% to OFI, 25% to OFO, and 57% to the underflow streams.

The excessive chromite reporting to the underflow of the conventional cyclone shows that the cyclone fails to cope with the density separation. In most of the circuits where the flat bottom cyclone has been installed, it was meant to have a high amount of chromite reporting to the underflow so that the chromite-rich stream can be processed separately from the silica-rich stream. The results in this study tend to indicate that the flat bottom cyclone does the opposite of its intended purpose in the UG2 ore circuits. However, it should be noted that no attempt was made to vary the design parameters in the flat bottom cyclone during the testwork. It is not known to what extent varying design parameters such as the spigot size, vortex finder diameter and length would give different splits to those shown here.

Application of the three-product cyclone

To make the three-product cyclone useful, the middlings product must be processed using a different process route. In the UG2 ore, silica with an average relative density of 2.7, the platinum group metal (PGM) carrying component co-exists with chromite–a component barren of PGM values. Chromite has a relative density of 4.5, which is significantly higher than that of silica[4]. In the UG2 ore concentrators the major problems caused by the dual density ore are:

- losses in the PGM recovery are associated with high amounts of plus 100 µm silica reporting to the flotation circuit
- mill capacity is taken up by a high percentage of fine chromite already in the sub- 100 µm range recirculating to the mill for further grinding.

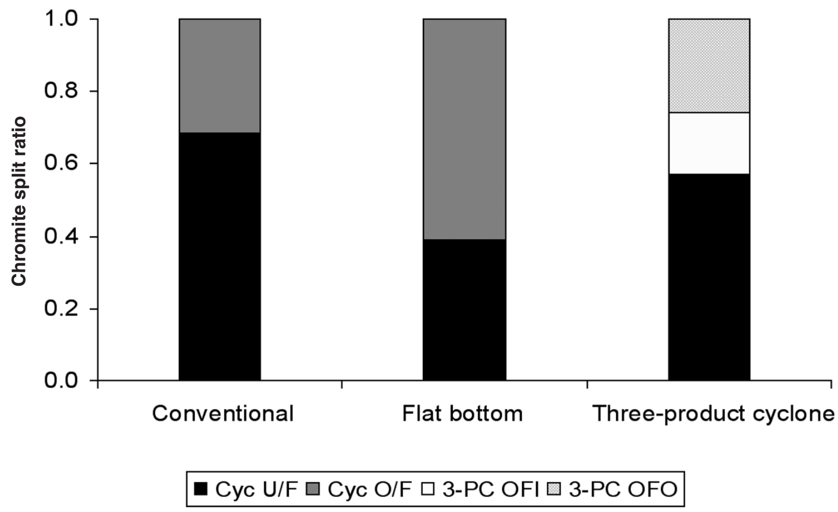

Figure 9. Average chromite splits to the respective cyclone product streams

The three-product cyclone can be used with the fine screens to screen out the plus 100 μm from the middlings stream. From the testwork conducted using a 600 mm industrial cyclone it was shown that on average 12% of the particles in the middlings stream are in the plus 100 μm size range. Examination of the component splits by size indicated that the middlings stream contained 25% of silica and only 8% of chromite in the plus 100 μm size range. The results from the industrial testwork presented by Mainza, *et al.*[4] indicated that the three-product cyclone can be used to provide a stream that could be screened using fine screening techniques to yield a screen O/S, which has more silica that can be sent back to the mill for further grinding and the screen U/S, which has more chromite that can be removed from the grinding circuit by combining it with the finer overflow that is sent for flotation[4,5]. The limitation with using fine screens on the overflow of the conventional cyclone is that they cannot handle high throughputs. The three-product cyclone has the advantage of providing a stream with the desired mass split for screening using fine screening techniques. Due to the flexibility shown by the three-product cyclone, a pilot plant was designed and built for conducting circuit trials to test the applications of the three-product cyclone in different circuit configurations.

To demonstrate the applicability of the classification system with the three-product cyclone and fine screens in the circuit, pilot plant trials were conducted at the Lonmin pilot plant located at the Karee concentrator. A schematic of the pilot plant circuit for the testwork is presented in Figure 10. The Pansep-fine screens used in the testwork are a mechanical self cleaning system of screens, which can be fitted with 100 μm apertures screen panels. This process route enables coarse silica to be selectively recirculated to the mill for further grinding and allows only the fine enough silica to report to the flotation circuit. The chromite, which is predominantly fine in the middlings, is removed from the grinding circuit through the Pansep undersize. The-three product cyclone can only be beneficial if something different is done with the third product to take advantage of the flexibility that is provided by having the third product, which is unique in terms of size distribution and component splits.

Figure 11 shows the size distributions for the three-product cyclone and Pansep screens. It can be seen that three distinct products were given by the three-product cyclone. Due to the intermediate size distribution and relatively small volumetric flow split, the middlings product provided an ideal feed for the fine screening operation using Panseps. A significantly coarser Pansep oversize was preferentially recirculated to the mill for further size reduction and the Pansep undersize containing sub-100 μm was combined with the OFI and sent for flotation.

A summary of the mass flow rates and percentage solids of the streams are presented in Table I. The aim of conducting the pilot plant trials was to determine the operability of the circuit with the two classifiers and the final product from the comminution section floated using the Flotability Characterisation Test Rig (FCTR). The case study was done on a primary application instead of the intended regrind application, resulting in a shift in the size distribution curves towards the coarse end.

The size distribution and mass flow results have indicated that a middlings product from the three-product cyclone can be screened on Panseps to give a Pansep oversize, which is predominantly plus 100 μm, which can be preferentially re-circulated for further grinding, and an undersize of all passing 100 μm that can be combined with the finer overflow. At the time of writing, the assays for PGMs, silica, and chromite from the pilot plant testwork were still outstanding, so the full results will be reported in future.

Observations from the testwork

The comparison of the performance of the conventional and flat bottom cyclones were made using the efficiency curves.

The actual and corrected efficiency curves obtained from particle size and flow rate data showed that:

- the conventional cyclone efficiency curves were steeper than those for the flat bottom cyclone, indicating that the conventional cyclone gives a sharper separation than the flat bottom cyclone
- the flat bottom cyclone gives a coarser cut size of 160 μm compared to 73 μm for the conventional cyclone
- the flat bottom cyclone had a small fraction of fines in the underflow stream, indicating that the quality of the underflow is better when the flat bottom cyclone is

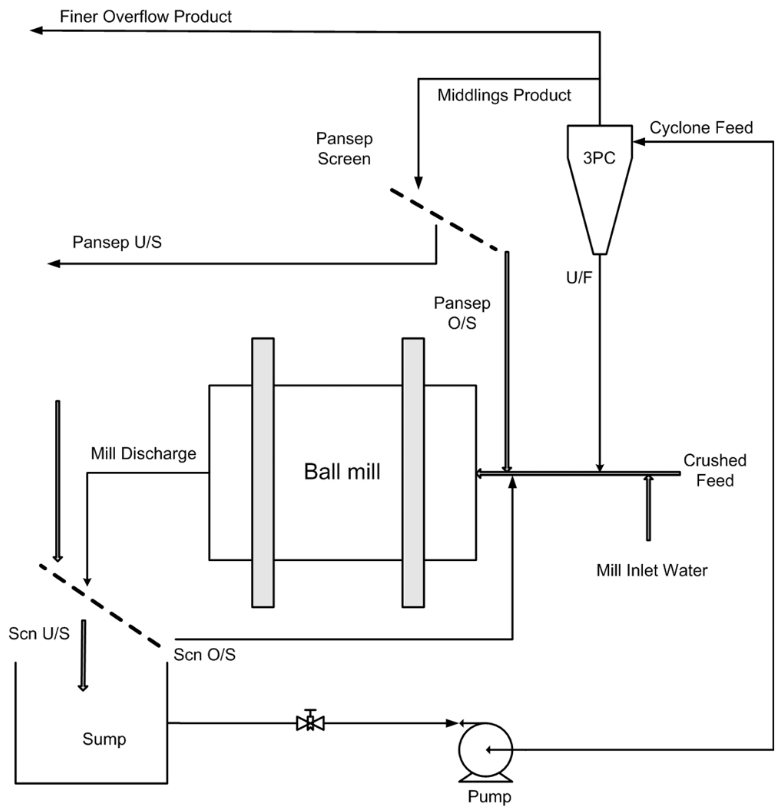

Figure 10. The pilot plant test rig set-up for application of the three-product cyclone

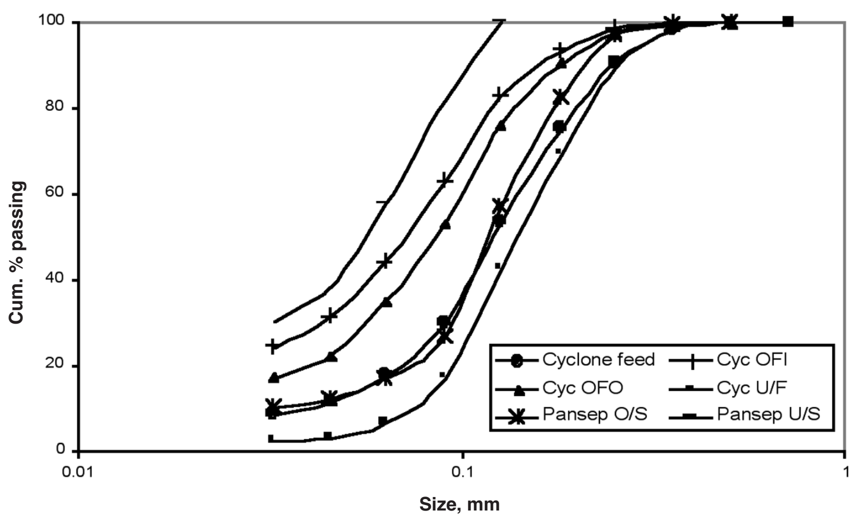

Figure 11. Particle size distributions for the three-product cyclone and Pansep screens obtained from the pilot plant tests

used, but the overflow contains a high amount of coarse silica.

The component efficiency curves showed that:

- the recovery curves for the conventional cyclone for both silica and chromite were steeper than those for the flat bottom cyclone
- due to the high density, the cut size of chromite was smaller than that of silica.

The mass split ratios have shown that:

- from the material in the feed, 70% reports to the underflow stream for the conventional cyclone and 30% for the flat bottom cyclone. This indicates that the

Table I
Stream information for the pilot plant trials

Stream	TPH solids		% solids	
	Exp	Bal	Exp	Bal
Cyclone feed	2.822	2.868	51.25	51.27
Cyclone OFI	0.559	0.559	31.04	29.69
Cyclone OFO	0.638	0.642	42.41	40.26
Cyclone U/F	1.667	1.667	78.40	78.71
Pansep U/S	0.513	0.509	33.56	35.43
Pansep O/S	0.136	0.132	31.50	32.95

recirculating loads are lower when the flat bottom cyclone is used.

- when the three-product cyclone was used, 30% of the feed material reported to the finer overflow stream, 20% to the middlings stream, and 50% to the underflow stream. The mass splits exhibited by the three are attractive for the application of reclassifying the middlings stream using fine screens to screen out the particles that are larger than the required size for maximizing recovery in the flotation process.

The component splits have shown that both the conventional and flat bottom cyclones are not suited for treating ore containing components with large differences in component density. The paper has shown that:

- the silica splits to the underflow were 40% for the conventional cyclone and 20% for the flat bottom cyclone, while 25% reported to the inner overflow, 40% to outer overflow, and 35% to the underflow streams for the three-product cyclone
- the chromite split to the underflow were 70% for the conventional cyclone and 40% for the flat bottom cyclone, while 18% to the inner overflow, 25% to outer overflow, and 57% to the underflow streams for the three-product cyclone
- an average of 25% of the silica in the middlings stream was in the plus 100 μm with only 8% chromite making the three-product cyclone attractive for the application of linking it with Pansep
- The middlings stream is ideal for screening on the Pansep with 100 μm screen apertures to yield a screen oversize that is predominantly plus 100 μm that can be preferentially re circulated for further grinding with the aim of maximizing the recovery of PGMs that would otherwise be lost if sent to the flotation circuit.

Conclusions

The work has shown that the conventional hydrocyclone and the flat bottom cyclone cannot be used to classify the UG2 ore to give the desired splits to the overflow by both size and mineral component. The work has highlighted that all the attempts to address the problems in the classification of the UG2 ore, using the conventional hydrocyclone and flat bottom cyclones, have not yielded the intended results.

The three-product cyclone has been shown to be superior, in terms of product size distribution, mass splits and component splits, to the conventional and flat bottom cyclones.

A classification system utilizing the three-product cyclone and fine screens can be used in the circuit, and pilot plant trials have shown that the system is operable with the UG2 platinum ore.

Acknowledgements

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References

1. COLEMAN, R.L. *Metallurgical testing procedure. Mineral processing plant design*. 2nd Edition. Mular, A.L. and Bhappu, R.B. (eds.) AIME, 1980.
2. MILLS, C. Process design and plant design for gravity concentration. *Mineral processing plant design*. 2nd Edition. Mular, A.L. and Bhappu, R.B. (eds.) AIME .1980. pp. 404–422.
3. MAINZA, A.N. and POWELL, M.S. Use of the three-product cyclone in dual-density ore classification. *IMPC Procedings*. Cape Town, South Africa. October 2003. pp. 650–664.
4. MAINZA, A.N., POWELL, M.S., and KNOPJES, B. Differential classification of dense material in a three-product cyclone. *Minerals engineering Journal*, May 2004, vol. 17, pp. 573–579.
5. KELSALL, D.F. A further study of the hydraulic cyclone. *Chemical Engineering Science*. 1953, vol. 2, pp. 254–272.
6. BRADLEY, D. *The hydrocyclone*. Pergamon Press. 1965.
7. SVAROVSKY, L. *Hydrocyclone*. Technomic Publishing Co. London.1984.
8. SCHMIDT, M.P. and TURNER, P.A. Flat bottom or horizontal cyclones—which is right for you? *World mining Equipment*, Sept 1993. pp. 21–22.
9. MORRELL, S. Evaluation of the separation performance of a new design of hydrocyclone. Chapter 7, Second Progress Report, JKMRC/AMIRA Project P9L. 1996.
10. BEDNARSKI, S. Three-product hydrocyclone for simultaneous Separation of solids both heavier and lighter than liquid medium. *Hydrocyclones Analysis and Application*. 1992. vol. 12, pp. 397–404.
11. WILLS, B.A. *Mineral Processing Technology*. Sixth Edition, Maxwell Macmillan International Editions (Pergamon press). 1992.
12. VALLEBUONA, G., CASALI., FERRARA G., LEAL O., and BEVILACQUA, P. Modelling for the small diameter hydrocyclones. *Minerals Engineering*. 1995. vol. 3, pp. 321–327.
13. SVAROVSKY, L. Critical evaluation of the simple ways of determining the cut size. Proceedings, International Conference on hydrocyclones. BHRA Fluid Engineering. Cranfield, 1980. pp. 37–47.