Mineralogical control of minerals processing circuit design

by M.A.W. Bryson*

Platinum group metals are extracted almost exclusively in South Africa from three very different zones in the Bushveld Igneous Complex, called the Plat, Merensky, and the UG-2 reefs. The Plat reef is currently being exploited only by Anglo American Platinum, whereas the Merensky reef is exploited by them, Impala Platinum, Northam, and Lonplats. The UG-2 reef, on the other hand, is also processed by these producers, but Kroondal and Barplats have operations that exclusively treat ore from this reef.

At present the extraction of pgms from ores in South Africa follows the traditional route of upgrading to a concentrate in a minerals processing circuit, further upgrading to a matte in a smelter, and final upgrading and separation of the individual metals in a refinery. Thus all operations that extract pgms require a minerals processing circuit, the design and performance of which is a topic of much interest, as it is a poorly understood and not a very efficient process in relative terms, compared to the other processes. Recoveries across the minerals processing circuit of between 75 and 90% are the norm.

The effective running of a pgm minerals processing circuit requires that the mining plan and concentrator design take into account specific mineralogical features of the ore. The objective of this presentation is to show how some of these features have influenced the design of pgm minerals processing circuits.

Dense media separators, spirals, screens

The first mineralogical feature to be discussed is mineral density. The chromite in the UG-2 reef has a density of around 4.6, whereas the silicate minerals in these reefs have densities from 2.8 to 3.4. This difference can be exploited in the minerals processing circuit to positive effect, but it can also have negative effects.

In mining the UG-2 reef, it has been found by some producers that, despite the fact that nearly all the pgm values sit within the chromitite-reef, that mining rates can be increased and thus costs reduced if waste rock above and below the reef is taken. On surface a significant amount of this barren waste can be rejected through the use of a dense media separation plant that exploits the density difference between chromitite and silicate-rich rocks. This has the effect of increasing the mill feed grade, so reducing the size of the mill and flotation plant, cutting down on the amount of chemicals needed, and even resulting in higher overall plant pgm recoveries. DMS plants exist on UG-2 operations today, and it is predicted that some of the new operations will include this technology.

Although the bulk of the pgms in the UG-2 reef occur within the chromitite layer, the mineral chromite does not carry a significant pgm content, and it can be separated and discarded after the primary milling and flotation stage. Some operations believe that by removing the chromite at this point, they can cut back on the size and cost of the secondary milling and flotation plant and, in addition, they have another source of revenue. The separation is thus currently achieved using a spiral circuit that exploits the differences in densities between chromite and silicate minerals, to separate them into two products. The decision on whether to put a chromite removal stage into a UG-2 plant design is based, however, on whether one can remove a significant amount of mass by this route without incurring a value's loss. This is not always the case and it depends on the mineralogy of the ore treated.

In most minerals processing circuits, classification is an important unit operation to ensure that values are liberated before being directed to the next unit operation, and as a method of improving on energy utilization. Cyclones are most often used in this application, as they are cheap and simple to operate. In UG-2 circuits, though, where one has minerals of different densities, a dense media effect occurs within the cyclone that causes coarser particles of the lower density fraction to preferentially report to the classified product. This material often contains values that require liberating and thus the process is inefficient. In addition, the chromite itself builds up in the mill and it escapes only once it has been milled fine. This is energy inefficient as chromite is usually liberated at below 200 microns and it is barren of value. Furthermore the requirement to keep the chromite levels of the final product as low as possible because of downstream processing constraints, means that chromite grinding should be avoided as the slime will tend to contaminate the concentrate via an entrainment mechanism.

These days the primary mill classification in a UG-2 circuit is often done with a 600 or 850-micron screen instead of a cyclone as it cuts on the basis of size only. Cyclones are, however, used exclusively on other ore types and in secondary grind applications due to the advantages mentioned above, but attempts are being made to improve fine screening technology so that they can at least be used in conjunction with cyclones to improve the overall size separation.

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Flash flotation cells

The next mineralogical feature to be discussed is the size of the valuable or value-containing mineral. Traditional flotation processes and equipment are effective over a limited particle size range, the range of which depends on the properties of the mineral. For most minerals this range is above 5 microns and below 75 microns. If liberated values do occur in the coarser size ranges, one would have to mill them more finely to recover them by normal flotation, and in the process of breaking these particle some fines are also created.

In Merensky ores in particular, some of the pgm containing particles are coarse and sliming of a mineral-like pentlandite through overgrinding can be a problem. A flotation device was thus developed that could operate on very coarse feeds, such as a primary mill discharge or cyclone underflow, and recover liberated values that otherwise would have been returned to the mill. A unit operation called a flash flotation cell was designed for this application and it is being used on a number of pgm operations to good effect.

Milling

The mode of occurrence of the values in pgm ores does influence the design of the minerals processing circuit. The fact that a significant proportion of the pgm values in these ores occur on the grain boundaries between the major mineral phases, and that some of these pgm values occur as 1 to 4 micron sized, discrete mineral phases attached to the grain edges of larger sulphide minerals, are used to influence the selection of a milling process.

The flotation kinetics, and thus its probability of ending up in the final concentrate, of a 20 to 75 micron base-metal sulphide mineral particle is significantly higher than a 2 micron platinum mineral, and thus one should try in the milling circuit not to detach these small pgm particles from the larger sulphide mineral. This is referred to as sliming the pgms and this problem can also occur when sulphide minerals are overground.

The objective of some milling circuits is thus to put sufficient milling energy into the primary milling stage to liberate the sulphide minerals from the main gangue minerals, but not an excess that may lead to a reduction in the amount of pgm values that are recovered through attachment to a major sulphide mineral.

At the same time, by only milling in the primary circuit to the grain sizes of the main mineral phases, the energy costs associated with milling the mineral rather than the rock phases is not incurred. Thus there are significant energy and operating cost savings to be attained through the use of fully autogeneous (AG) mills that use the presence of coarse hard rocks in the feed to do the milling. Variations on this theme are to use run-of-mine ball milling or to use AG mills with pebble ports, depending on the specific features of the ore under investigation. Rod mills also find applications where a coarse primary mill product is required or where the use of a DMS plant has necessitated the partial crushing of the ore.

Secondary milling

Another mode of occurrence of pgms in these reefs are as partially-locked particles in the silicate minerals and this can influence the design of the minerals processing circuit if this mode is significant. Under some circumstances these particles can be made to float in the rougher stages and to subsequently congregate in the cleaner tails streams. The use of ultra-fine milling on this material can liberate these pgm values, which can then be made to report to the final concentrate. The very fine nature of this material, though, dictates that specialized mills are required for this application and some of these are under evaluation by some producers at present.

If some of the pgm values are totally locked in the silicate matrix then it may not be possible to recover them in the primary flotation stage, and a secondary milling stage needs to be installed. At this point the milling of mineral rather than rock is required, and the energy used can be higher than that used in the primary mill. The effectiveness of these mills is often not as good as desired and research on improving the performance of this circuit is ongoing. Areas being looked at currently are whether the different hardness of the minerals can be exploited, and whether the size and type of media used in these mills is important.

Gravity separation

In certain pgm ores some of the values occur in relatively coarse distinct pgm mineral and alloy phases, like sperrylite, and isoferro-platinum, that are often referred to as the metallics. These phases have densities that are significantly higher than the other mineral phases in that the densities range from 11 upwards. Some of these pgms can be upgraded into a special concentrate using various gravity-based methods.

Since it is suspected that some of these pgms do not respond well to flotation when milled fine, and it is known that a concentrate with a grade high enough for it to be sent directly to the refinery can be produced from them, there is an incentive to install gravity separation devices in the milling circuits of plants treating some Merensky and Plat reef ores.

In some of the early Merensky plants, corduroy tables were used to concentrate these values, but today there are devices like the Knelson and Falcon concentrators that are potentially more effective and secure in this application. These devices use a centrifugal force to enhance the separation. They do have limitations, though, and they are not effective on ultra-fine pgm minerals or on feeds that contain large quantities of high-density gangue phases like chromite.

Flotation residence time and circuit configuration

By virtue of the small size of a significant fraction of the pgms in these ores, one finds that a proportion of the value is classified as slow floating, and steps need to be taken in the plant design to accommodate this. For example, the primary rougher flotation residence times in plants can be as long as one hour, which is much longer than the 20 minutes that one may give to a coarse sulphide mineral flotation process. The same applies to the secondary circuits where the fraction of slow floating mineral would be even higher. The same arguments apply to the cleaning circuits, and large flotation residence times are assigned to these stages. In this case, the fact that product recirculation occurs means that it is possible to build up high circulating loads between stages that can be used to advantage to ensure that one can enhance concentrate grades and pgm recoveries, provided one has very tight control of the rate of concentrate production.

Some producers rather run very complex circuit configurations designed to balance the flotation rate of a particle with the residence time it has in the plant. Thus fastfloating particles can go straight from the rougher to the final product, whereas slow floating particles can go through three stages of cleaning.

Power input to flotation cells

It is now generally accepted by the industry that the slow flotation kinetics of some of the pgm particles can be overcome to some degree by insuring that the adsorbed power by slurry in a rougher flotation cell is in the region of 3 kw/m^3. Power is required to ensure that coarse particles are kept in suspension, but it is also believed that the flotation rate of fine pgms is enhanced through this mechanism. There is also the possibility that the power input overcomes aspects such as fine particle agglomeration, and it may also assist in the removal of coatings or rims from particles. It is of interest that, contrary to trends elsewhere, column flotation cells do not find acceptance in the pgm industry as the recoveries across these cells is believed to be poor.

Flotation cell design and plant control

In response to the demand for more efficient flotation machines to cope with the flotation kinetics of more difficult materials, the design of new generation flotation machines are circular, large, and they incorporate methods to control the froth removal rate. Each cell is independent, and control of air rate, pulp level, and froth removal rate is possible.

Plant control systems are also now in place that allow the operators greater flexibility in setting and running the plant. Examples of these are the Floatstar plant level control system that allows plants to be stabilized faster and to cope better with feed and flow disturbances, and the Frothcam system that determines the characteristics of a froth so that an operator can set his plant operating parameters to achieve specific froth features.

Reagents

An important part of all minerals processing circuits are the reagent make-up and distribution facilities. Four classes of reagents are used in pgm circuits. Copper sulphate is often used as an activator of sulphide minerals like pentlandite and pyrrhotite, but it is also believed to be important as a froth modifier. Collectors, which are added to ensure that the required particles attach to air bubbles, vary in type from xanthates to dithiophosphates and thionocarbamates, and they are often added as combinations. Depressants, of which there are a wide variety available, are added to enhance the product grade by reducing the recovery of naturally floatable gangue minerals like talc. Frothers are added to create a froth layer within which slurry drainage can take place and the final product upgrading occurs.

The types, dosages and addition points of these reagents are different for all operations and they depend on the ore type being processed and the specific requirements of the downstream processing facilities. Within most operations, the feed ore is reasonably consistent and, once the reagent suite is fixed, the plant is controlled mainly by varying the depressant and frother dosages. There are, however, major differences in these values between plants treating different ores, and between plants treating the same ore from different areas.

Conclusion

It can be said that the challenge of designing the optimum pgm minerals processing circuit starts with the understanding of the basic mineralogy of the ore treated. The fact that there are no circuit clones in this business is a reflection of the variability in the mineralogy of pgm ores. ◆

ARC support provides timely fillip for flotation research

The Julius Kruttschnitt Mineral Research Centre is poised to advance the fundamental understanding of that most difficult aspect of minerals engineering—the flotation process—thanks to an AUD $1.78 million grant from the Australian Research Council.

Until now, flotation research undertaken through the AMIRA International P9 project, of which the JKMRC is the major researcher, has been undertaken largely through the support of industry funding.

Official Australian government support through the ARC is a timely fillip for the flotation research team at the JKMRC led by Professor J-P Franzidis and Dr Emmy Manlapig.

According to Professor Franzidis the grant is a 'big win' for the researchers, allowing flotation research engineers to get to grips with some of the fundamentals underlying the JKMRC's successful approach to the engineering modelling of flotation.

The $1,785,778 grant over four years, which commenced at the beginning of July 2004 is the largest ARC grant in Queensland for that funding round, and was the largest component of ARC funding allocated to The University of Queensland.

'It will involve dominantly the JKMRC, with contributions from Professor Graeme Jameson at the University of Newcastle and Professor John Ralston and colleagues at the University of South Australia's Ian Wark Research Institute,' Professor Franzidis said.

'A lot of work went into the proposal, and our collaborators in Newcastle and Adelaide played an important role,' he said.

Professor Peter Hayes from the Pyrometallurgy Research Centre at The University of Queensland—also a previous recipient of a substantial ARC grant—played a key role in the preparation of the JKMRC submission.

Professor Franzidis said that froth flotation is arguably the single most important unit operation in mineral processing, being the method by which metals such as copper, lead, zinc, gold, platinum and many others, as well as fine coal, are recovered from ores worldwide.

'The problem for the mineral processors is that flotation is still not well understood at the fundamental level, leading to significant metal losses and an unacceptably high environmental impact,' he said.

'New flotation plants are sometimes inadequately designed or may take several years to commission properly because of this fundamental lack of understanding of the underlying process.'

He said that many operating flotation plants run inefficiently for long periods of time because optimization is done on a trial-and-error basis rather than being based on established scientific principles.

'A major advance in our knowledge of flotation will allow better resource utilization through improved value recovery and reduced metal losses to tailings, as well as reduced energy consumption and therefore a reduction in greenhouse gas emissions.

'A further benefit would come from more benign disposal practices leading to improved water recovery and dust control through the disposal of coarser waste particles.'

The ARC linkage funding will be attached to the AMIRA P9N project which aims to achieve a quantum improvement in the understanding of flotation, delivered as a property-based particle floatability model that can predict flotation response accurately from measurable properties such as particle size, mineral composition, liberation, and hydrophobicity.

Professor Franzidis said the model would be developed from results of controlled laboratory-scale experiments using novel methodologies developed by the JKMRC, the Ian Wark Research Institute and the University of Newcastle on single minerals and samples of ores collected from industry partner sites, and validated using data from fieldwork programs at the same industry partner sites.

'The timing and sequence of implementation of the projects have been selected carefully so that they will, at the same time, address the immediate problems faced by the industry partners and provide the data required to develop the fundamental models.'

He said each industrial site-based project planned across four countries—Australia, Brazil, Chile, and South Africa—would contribute to the overall program.

Through AMIRA, ten Australian mining or mining technology services companies have committed support as industry partners to the flotation elements of the program, in the form of financial and in-kind support of postgraduate student training, software development and the fieldwork projects that are essential to setting the research in a practical context.

Professor Franzidis said that with ARC support the researchers could now take the science underpinning flotation engineering to a previously unattainable level.

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