PRECONCENTRATION OF UG2 PLATINUM ORE: ECONOMIC BENEFITS TO MINE, PLANT, AND SMELTER

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Abstract

Mining and plant disciplines can benefit from pre-concentration of UG2 platinum ores in a dense medium separation (DMS) plant. The main benefit of DMS is the selective discard of waste from the feed stream, thus improving project economics while reducing the power and water requirements for processing.

On the mining side, with the correct combination of variables, implementing DMS as a pre-concentration step can reduce cut-off grades and, as a result, increase ore reserves. In addition, the use of DMS technology gives the mine team the opportunity to consider alternative mining methods for an operation.

The challenges of balancing the mining tonnage, methods, and resulting grades with the process plant size, recoveries, and DMS discard volumes have resulted in the development of a model to optimize value on new projects or existing operations. This paper will focus on these benefits from a mining and plant perspective, quantifying the water and power savings, and look at the economic benefits of pre-concentration and the effect of metal prices, plant feed grade, and DMS efficiency in different mining environments.

Introduction

The quantity of UG2 ores treated over the past decade has increased dramatically. The increasing scarcity of high-grade resources has forced the evaluation of lower-grade deposits.

Power supply constraints in South Africa and high energy costs elsewhere in Africa demand that pre-concentration alternatives, such as dense medium separation (DMS), be explored to reduce the consumption of power and water on a plant, with a final objective of improving overall project economics.

Project economics can also be improved through capital expenditure (capex) reductions on the milling and flotation sections of a plant as a result of the lower tonnages treated downstream of preconcentration.

The inclusion of a DMS in a plant circuit can also allow for more flexibility in the selection of a mining method which constitutes a large portion of the overall capex and opex cost on a UG2 operation.

The above factors have resulted in preconcentration methods such as DMS and X-ray transmission (XRT) and X-ray fluorescence (XRF) sorting being tested as economical alternatives more frequently. Metallurgical testing laboratories have confirmed this trend by reporting significant increases in this type of test work.

DMS technology

The DMS process is a tried and tested technology tracing back to the 1940s. Initially, it was more popular on coal, diamonds, iron, and chrome. The benefits of the process have resulted in it being used in gold, lead-zinc, copper and, eventually, platinum plants as well.

The process itself is straightforward and is accommodated by a relatively small plant footprint. Of the commercially-exploited platinum reefs mined in South Africa, the UG2 chromitite reef has a much higher density than the silicate waste fraction in both the hanging- and footwall, and this difference is used to separate the reef from the waste.

A high-density ferrosilicon medium is made up at a certain density, mixed with the deslimed ore, and gravity fed to a cyclone at a defined pressure (Figure 1). The rest of the process is designed to recover medium; maintain density, stability, and viscosity; and discard any circulating fines in the <1.5 mm to 2 mm fraction. This has been well documented in previous papers on the subject[1, 2].

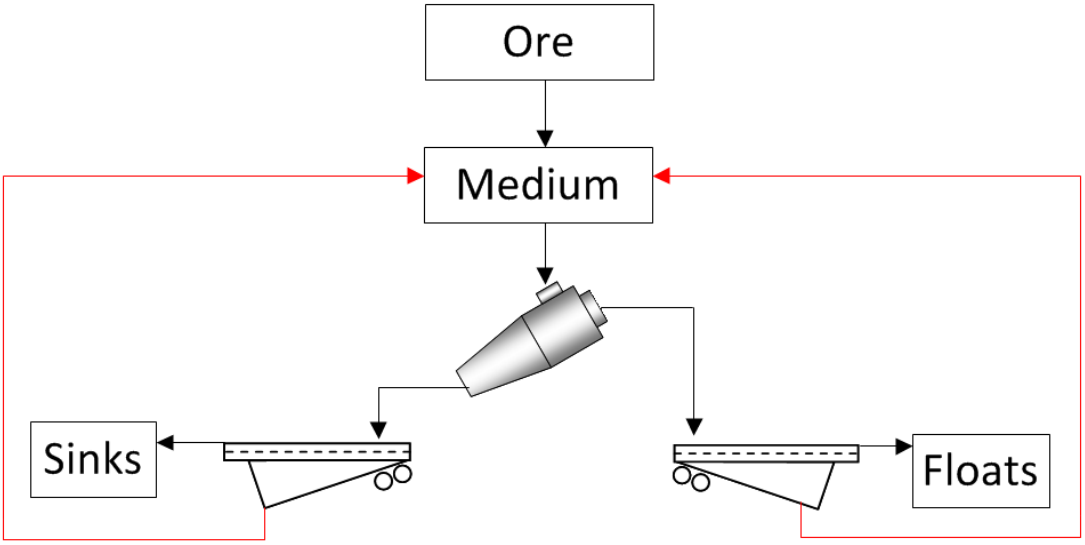


Figure 1-Typical ore and medium flow in a DMS

The classification in the DMS cyclone is driven by the density differential of the reef and waste materials, facilitated by the selected ferrosilicon density. Operating densities in a DMS are controlled by designing a 'rising density' circulating medium circuit which is continuously diluted to the correct medium density by topping up with water. This water is discarded and combined with the fines from the feed preparation screen before the DMS.

The main water and solids routes are indicated in Figure 2. The only water loss on a DMS circuit occurs as inherent surface moisture of the discard or 'floats' fraction. As this is typically +2 mm - 30 mm on UG2, the dewatering on the drain and rinse screens is effective and minimal quantities of water are discarded to the DMS waste stockpiles.

PGM losses are incurred with the material leaving the plant in the DMS floats stream.

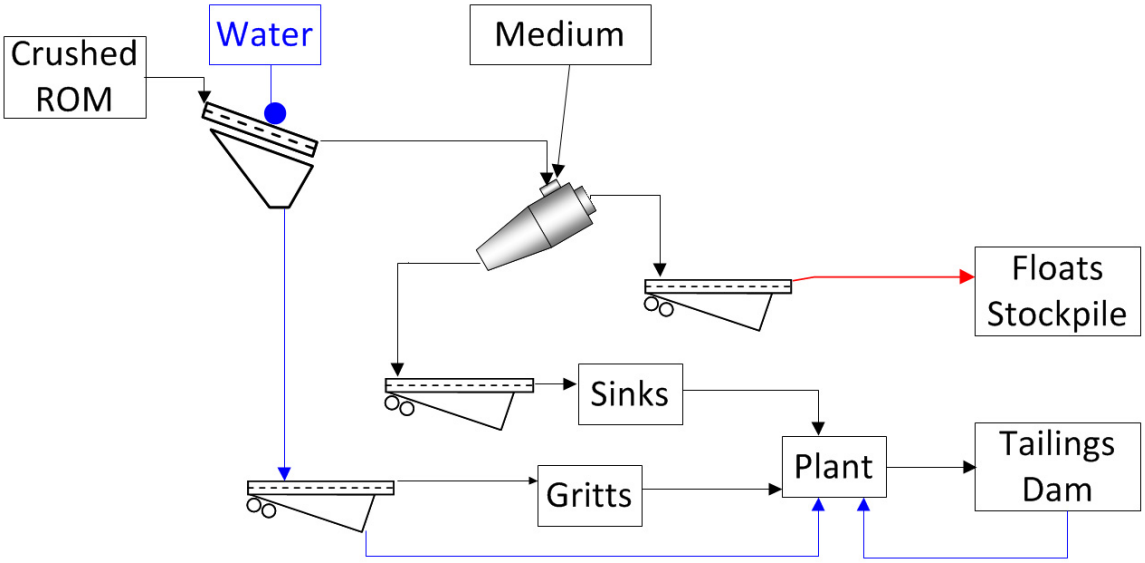
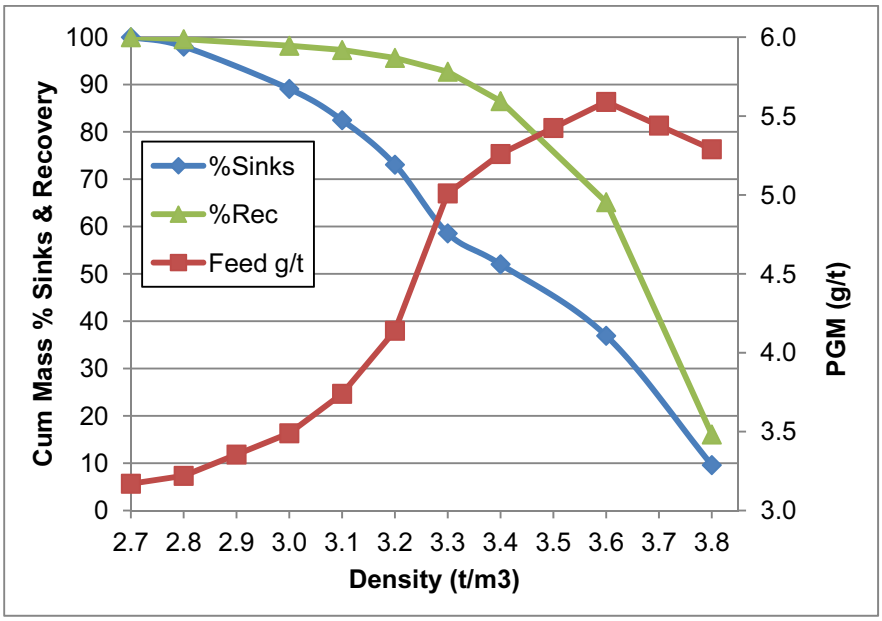


Figure 2-Main ore and water flows in a DMS

DMS response

The process tool used to determine the mass split at different densities is the washability curve that is generated from heavy liquid separation (HLS) test work. A 10 kg to 20 kg sample is statically separated at different densities and the grades and mass splits are recorded at each density.

Figure 3 illustrates the test work results received for HLS test work undertaken on a UG2 ore from the eastern limb of the Bushveld Complex.



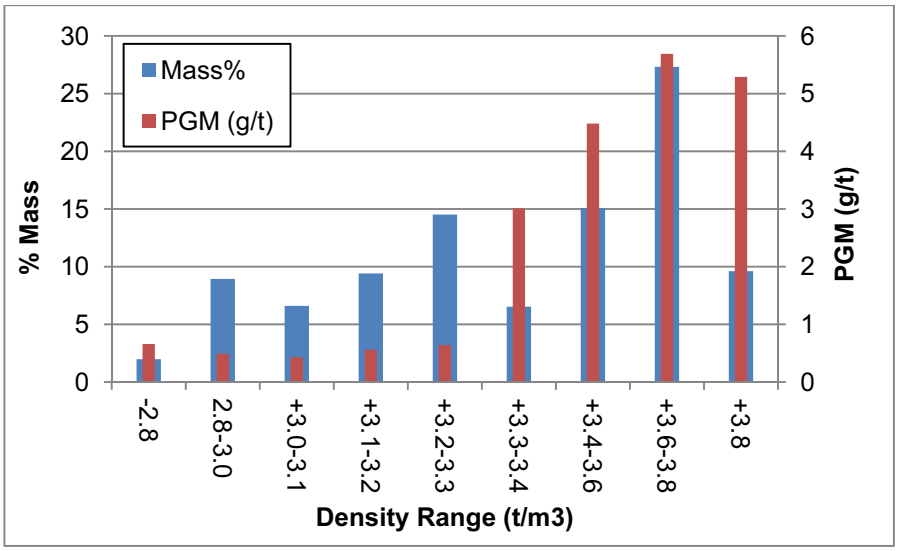


Figure 3-Typical washability curves on a UG2 ore

The suitability of the ore for the DMS process can be assessed from these curves. If the same data is plotted on a DMS efficiency curve, the rate at which mass is discarded in relation to recovery is obtained. Figure 4 shows the responses of four DMS processes with different efficiencies simulating four different ore responses, which are used in the case studies to follow. Response 'A' is the best DMS response, proceeding to the lesser efficient responses, shown as B to D.

The HLS example, shown in Figure 3, corresponds to the B-curve below.

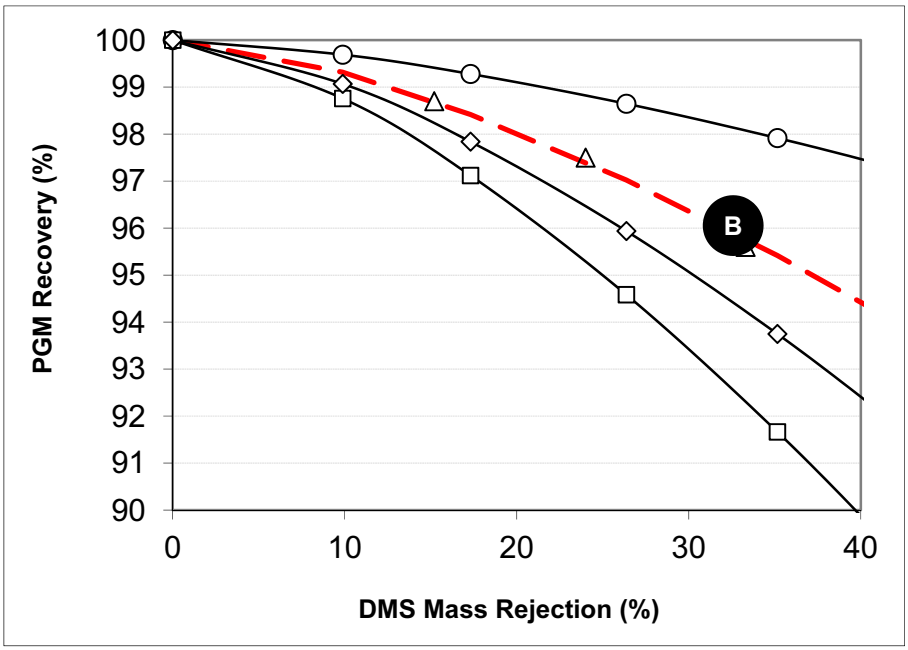


Figure 4-Typical DMS efficiency curves derived from HLS test work

Laboratory-scale HLS test work provides a fair indication of what could be achieved in theory. However, experience has shown that liberation and breakage functions play a role in the efficiency of the HLS tests. A core sample does not always break in a laboratory crusher as ROM would break on a plant crusher.

For this reason, a modular plant designed for diamond core testing has been altered by DRA Mineral Projects to enable pilot-plant testing of crushed ROM ores on site and has successfully been tested on chrome-bearing ores. Figure 5 is a recent photograph of this plant. Testing ore through the pilot plant will provide improved metallurgical data to better characterize the response in a DMS.

Figure 5-Pilot plant for DMS tests

DMS application

The application of DMS preconcentration, and its success, is very site- and ore-specific. DMS can be implemented on greenfield projects or be considered for brownfield expansions.

On brownfield projects, a DMS and crushing circuit is typically installed between the primary crusher and primary mill. Introducing DMS to an existing operation allows the metal throughput for the existing plant to be increased by treating more ROM material through the DMS, while maintaining the same tonnage throughput through the existing plant treating a higher grade, 'softer' ore. Typical applications would be:

- An existing operation wanting to increase production
- A plant that is struggling with mill throughput. DMS does not need to treat the full ROM stream; a smaller DMS plant can be implemented on a portion of the ROM stream with the downstream benefits removing the mill throughput bottleneck
- A change in mining grade. A DMS installation can render the downstream plant less sensitive to changes in the ROM envelope
- Low-grade waste dumps or development reef that have not been milled previously could, with fluctuations in metal prices, become a viable option for processing with the inclusion of a DMS plant, although this has not been implemented on a UG2 ore yet
- With an orebody located far from the processing plant, a significant reduction in transport cost could be realized if the ROM material is crushed and treated in a DMS situated close to the shaft or pit, and only the high-grade sinks transported to the plant. Consideration should, however, be given to the natural fines fraction, as that would need to be pumped to the plant or discarded

- A plant with a tailings storage facility (TSF) that is full or too small to handle future tonnages. A DMS circuit can be introduced to reduce the feed to the TSF by rerouting low-grade waste to a stockpile dump. Generally, it is easier to store coarse sizes of rock with minimal water as opposed to a wet ultra-fine slurry. Coarse material is more stable, so a smaller footprint is required with less consideration required towards drainage and topography.

With new greenfield projects, significantly more options are available in terms of implementation, which can provide numerous economic or environmental benefits, such as:

- Reduced overall capital cost for the processing plant. Capital required for the DMS is offset by savings in a smaller mill and float plant, as well as smaller TSF
- Reduced operating costs, due mainly to reduced power and water consumption
- The power reduction effect of incorporating DMS could result in a lower power application submitted to Eskom, which could ease the approval process
- The reduction in water requirements could also benefit the water application processes to water schemes. With the water supply shortages experienced in South Africa at present, projects often have to rely on more than one costly source for supply
- With a slow mining ramp-up on a modular design concentrator plant, a DMS can, for instance, be used to defer the capital of the second module
- Mining method and cut could be balanced with the plant feed grades and throughputs to optimize overall project value
- The inclusion of DMS could result in smaller footprint required for the TSF.

Techno-financial evaluation

To quantify the benefits of DMS implementation, a techno-financial model was developed and two hypothetical case studies are discussed in the paper. The model considers mine-to-smelter indicative capital costs, operating costs, PGM losses, as well as power and water consumption for various DMS efficiency scenarios, and rejection strategies.

Techno-financial modelling provides a tool for project teams to integrate activities along the value chain and ensure maximum value add. This is important since there is often a disconnection in focus between the mining and processing teams. To optimize overall project value or economic returns, focus should not be on just one area in the value chain.

In the model, the differential cash flow, over life of mine, is compared for two options (with and without DMS). This enables the effects of a variety of technical and economic variables, and the sensitivity to basket prices and DMS response in relation to DMS rejection rates, to be assessed.

The model is dynamic in that as the DMS rejection rate changes, the subsequent effect of the change is accounted for in terms of:

- Plant operating and capital costs
- Mining operating costs for mechanised *versus*. conventional mining methods
- Bond power (milling power) and pumping power reduction
- Water usage
- Smelting costs
- DMS recovery (operation specific and obtained from HLS or pilot test work)
- Overall plant recovery and concentrate grade based on plant feed grade improvement.

Hypothetical case studies

To demonstrate the effect of DMS concentration, two examples based on typical capital and operating costs for UG2 platinum mining have been explored.

- Scenario 1: Operation with and without DMS in a typical UG2 MF2 plant. This could represent a brownfield expansion project, where mining output is increased without any changes made to the mining method or the mill and float plant

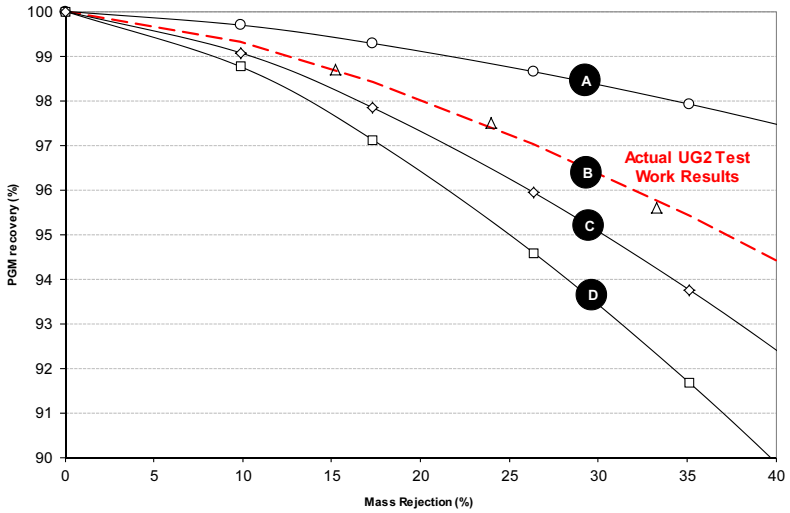
- Scenario 2: Two mining and processing methods are compared for a typical greenfield project. Mechanized 'wide-cut' mining with DMS preconcentration is compared with conventional 'narrow-cut' mining and no DMS ahead of milling and flotation.

For the scenarios to be described, plant feed rates were varied between 250 kt/month and 200 kt/month, with grades ranging between 2.5 g/t to 4 g/t. A typical PGE split was used with a Pt:Pd of around 1.8. Basket prices varied between R150 000 and R500 000 per PGE kilogram recovered.

A life of mine of 10 years was used in the analysis.

Final grades and concentrate volume are determined based on a simplistic mass balance and grade-recovery curve for a typical UG2 ore. Smelting costs and energy are also included in the model, where a specific smelting energy of 900 kWh/t has been used.

The model aims to assess the benefits of DMS preconcentration for various basket price scenarios, HLS response scenarios (A,B,C,D as in the curves in Figure 6), and for varying DMS rejection rates (i.e. varying DMS separation densities).



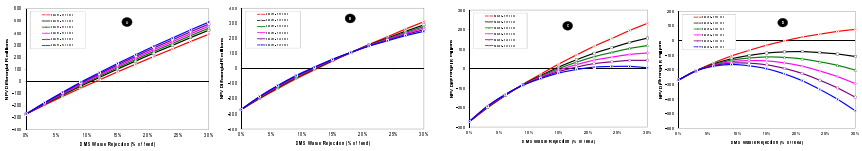


Figure 6-DMS response and differential project NPV

Figure 6 shows various HLS efficiency response and shows the corresponding DCF curves as will be discussed.

Plant operating cost

Plant operating cost estimates used in the financial model are based on industry norms and were calculated from first principles. The cost estimates for a typical UG2 plant (200 kt/month) and an estimate for a plant that has a DMS is show below in Figure 7. The curves show the plant operating cost benefit as a function of DMS rejection. The benefit is derived from a reduction in power consumption, water consumption, and reagent usage.

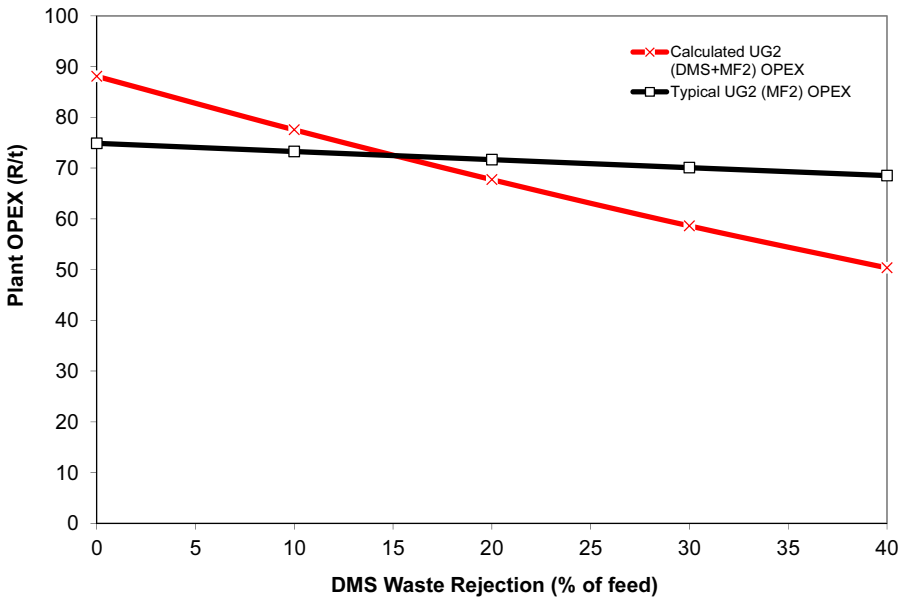


Figure 7-Model OPEX for 200 kt/month MF2 UG2 circuit (with and without DMS)

Reduction in plant power consumption

As a result of waste rejection ahead of processing, less ore is milled and pumped through the plant (ultimately to a TSF), providing significant power savings. A further benefit is the reduction in power consumption as a result of competent waste rejection ahead of the milling step (lowering the overall Work index of the material being milled). The DMS will produce softer sinks and harder floats. Milling only the softer sinks therefore results in additional savings. Milling is the largest power consumer on a UG2 plant, and the benefit derived from preconcentration is demonstrated in Figure 8. For the model, a power cost of R0.27 per kWh has been assumed (the use of DMS preconcentration is even more pronounced for base metal concentration projects in Africa, where self-generated power costs between US$0.2 – 0.4 per kWh).

The power savings as a result of DMS rejection not only improve operational expenditure, but also make entry into the industry easier due to reduced power demand.

Reduction in plant water consumption

The rejection of waste ultimately results in the TSF receiving less material and therefore less water. With less water reaching the tailings dam, losses as a result of interstitial lock-up, evaporation, and seepage are minimized. Processing less tonnage through the plant also requires less water.

The power and water savings are clearly demonstrated in the operating cost estimates (Figure 8 and Figure 9).

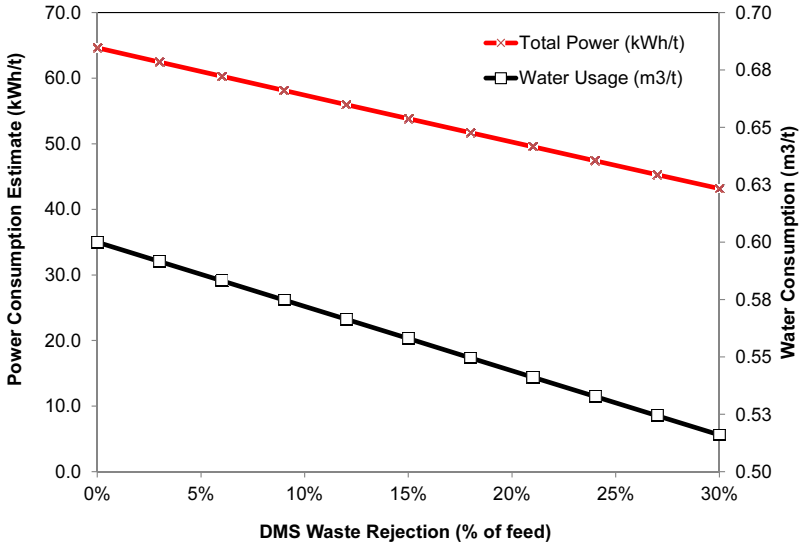


Figure 8-Effect of DMS rejection on plant power and water savings

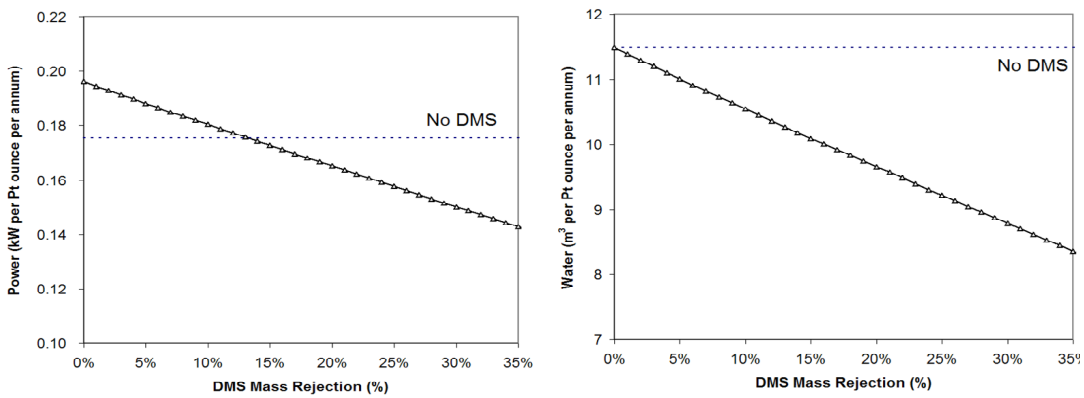


Figure 9-Specific power and water reduction resulting from preconcentration

A water cost of R13.0 per cubic metre has been used in the model.

Capital costs

The plant capital cost estimation was based on the DRA Mining Projects database together with the mining model estimates for the capital cost differential between a typical mechanized and a conventional operation. The plant capex will naturally reduce as the DMS rejection rate increases. In the case studies explored in this paper, two scenarios are evaluated.

Mechanized mining with DMS and smaller processing plant is compared with a conventional mining operation with a larger processing plant. The relative capital costs for the various options analysed are shown in Figure 10.

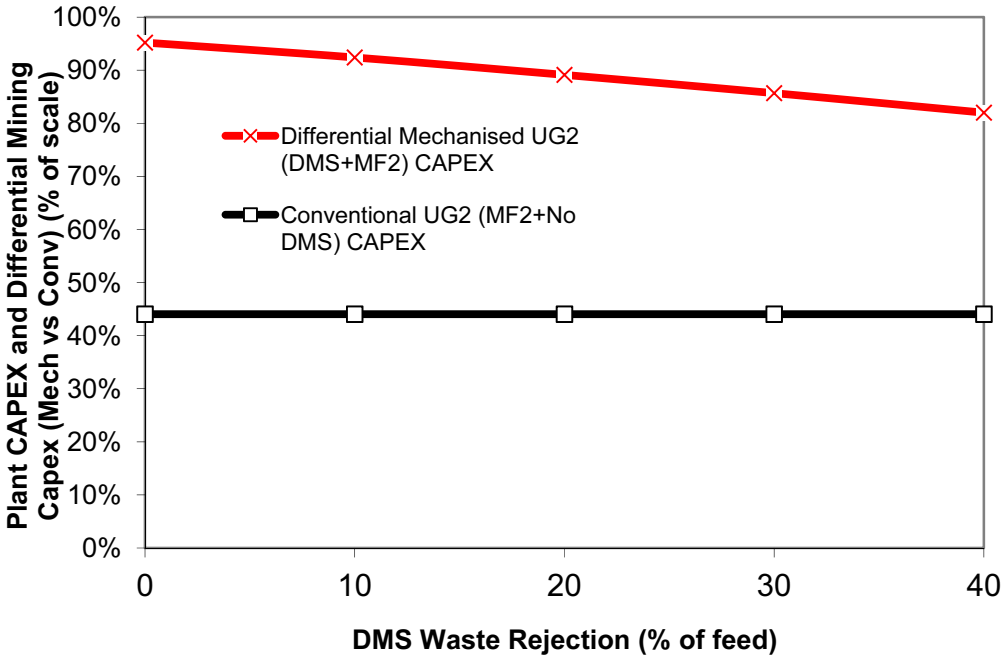


Figure 10-Mining (differential capex only) and plant capex estimates

Mining method and cut

UG2 reef often has split reef facies. In cases like this, the UG2 main chromitite is divided into two separate units, UG2A and UG2B. There could also be a leader chromitite seam that can contain good grades. These split units are normally separated by a pyroxenite waste parting of variable thickness.

Taking geotechnical data into consideration, a safe, economical mining cut needs to be determined. With the possibility of DMS a wider selected mining cut at a lower grade can now be extracted economically where previously *in-situ* ore would have been left. The additional hanging- or footwall tons will increase the OPEX cost on the mining but, with the wider inclusion, additional ounces can be expected.

Table II indicates a typical reef section that was used for the analysis. The characteristics can varied in the model to represent site-specific ore and varying geological features. The density differential should be noted, as a cut-point of around 3.30 would selectively send only high-grade material through to the plant.

Mining capital and operating cost

A wider cut could lend itself to the use of mechanized mining, should all other technical criteria, such as reef dip, roll, depth, and width, be met.

Although the initial capex for a mechanized mine is higher (machinery) than for conventional mining methods, the mechanized methods are preferred from a safety point of view, and also require significantly less labour. This in itself reduces the likelihood of mine accidents.

Another advantage of mechanization is the lower operating costs. In addition to the reduced units costs incurred through economies of scale, a further step reduction in mining costs is offered through the implementation of mechanized mining. Mechanization can often be employed only at selected mining widths above 160 cm.

The mining opex estimates used in the model are shown in Figure 11. The data is taken from a recent case study and indicates the unit operating cost step change between mechanized and conventional mining.

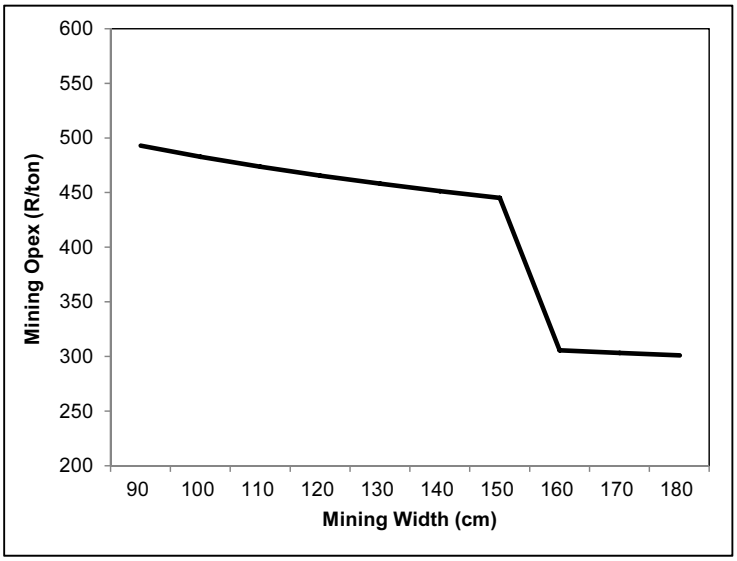


Figure 11-Mining opex *vs*. width mined

Scenario 1: Typical brownfield implementation

This example demonstrates the results of implementing DMS on an existing mine and plant, or alternatively d the effect of DMS alone with a constant mining approach. It is assumed that the mining method is already fixed, and production is 200 kt/month.

The overall project value is then analysed without and with a DMS in the circuit at various DMS efficiency cuts (A ,B, C ,D).

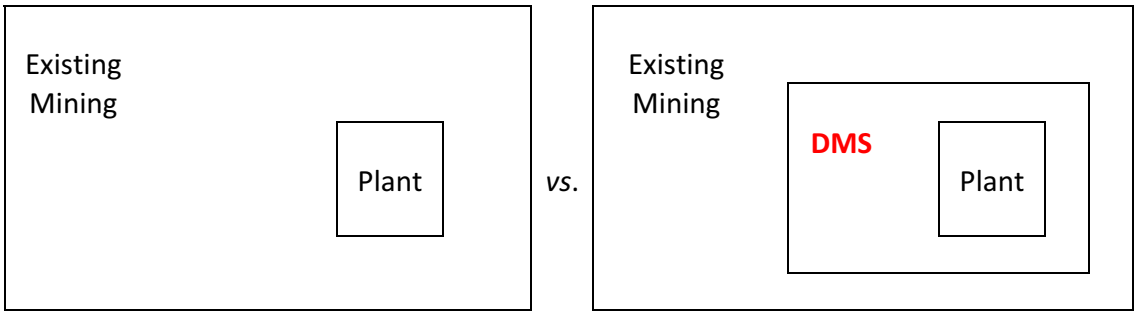


Figure 12 shows the differential NPV (10 per cent real) for various rejection rates and DMS efficiency scenarios (A being the most efficient) and for various basket prices. These scenarios should be viewed with reference to Figure 6.

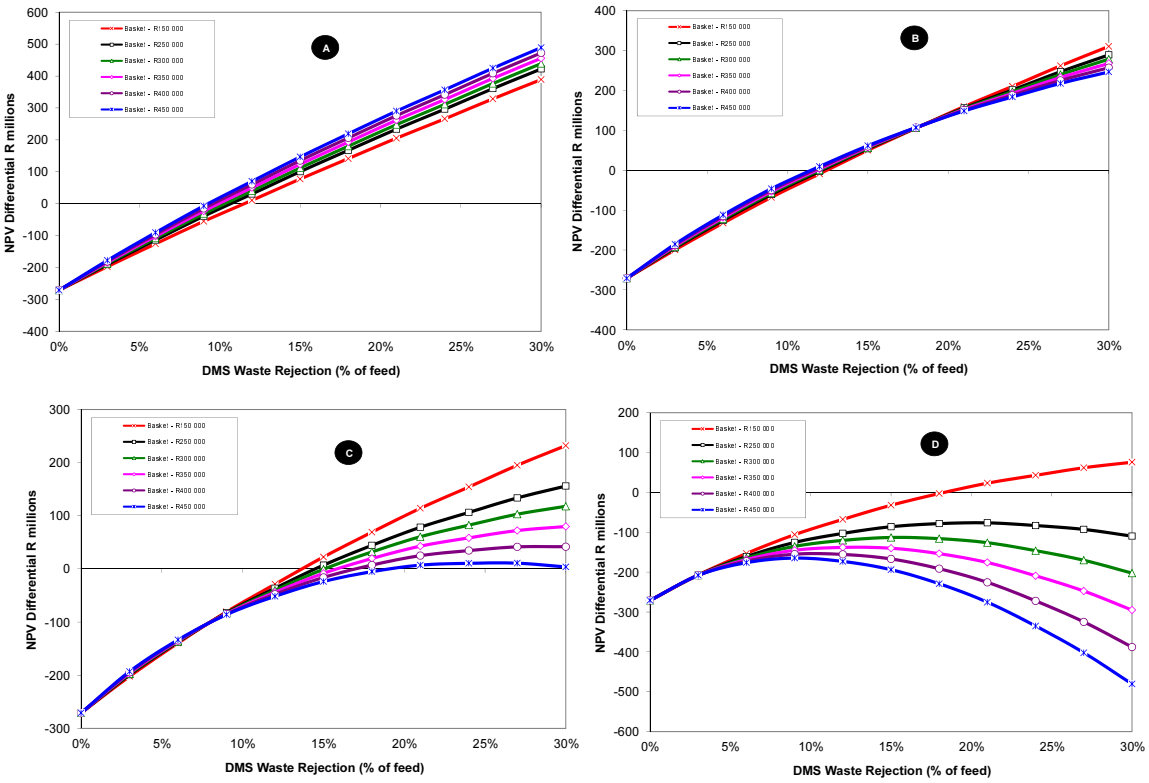


Figure 12- Differential NPV analysis for various DMS rejection rates, rejection efficiencies, and metal prices. Comparing an constant mining method, but processing with or without preconcentration

A negative differential NPV indicates no benefit from preconcentration, but rather value destruction. In an efficient DMS operation (A and B DMS response) it can be seen that value is added to a project for all metal price forecast scenarios, as long as a rejection rate of more than 10 per cent to 15 per cent is targeted by the mine. Efficient waste rejection of 30 per cent would see around R400 million improvement in project NPV, for the DCF inputs used.

It should also be noted that the high basket price inverts as the DMS efficiency drops from the efficient A to the less efficient B scenario. This indicates that the benefits of the DMS are more profound at lower metal prices, or alternatively for low-grade deposits

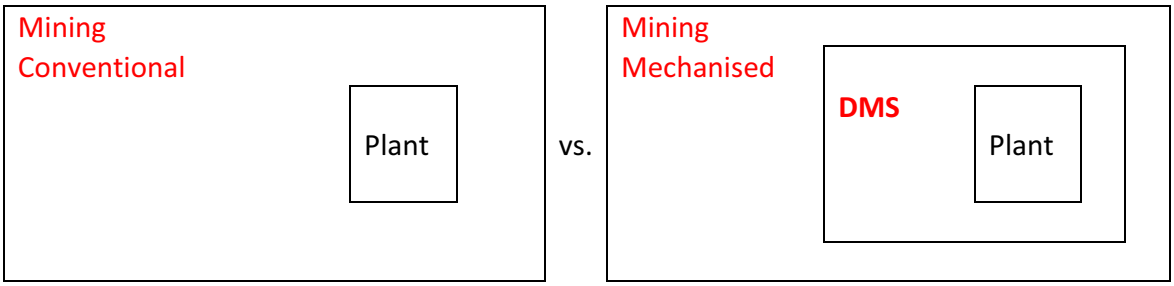
For the lowest-efficiency DMS operations (C and D), it can be seen that DMS becomes attractive only when metal prices or plant feed grades are low. The results clearly show that the use of DMS as a preconcentration tool depends on the:

- Metal price and plant feed grade
- DMS efficiency
- DMS rejection rate.

DMS clearly benefits low-grade operations, and could result in significant project value-add, not only by improving the overall project economics but also, since it requires less power during start-up (up to 20 per cent installed power reduction), simplifying Eskom power applications.

Scenario 2: Greenfield implementation

In this example, conventional mining at 200 kt/month with no DMS is compared to mechanized mining with DMS preconcentration ahead of the mill and float plant.



The model was altered to evaluate the effect of a mining change with DMS preconcentration, again for varying DMS efficiencies, metal price forecasts, and rejection rates in the DMS.

The mining operating and capital cost differentials are included in the model. For the exercise, the mining capital differential for mechanized and conventional mining was estimated to be around R1 billion, but this would naturally depend on many factors, including depth of resource, ground conditions, and angle and nature of the reef.

The modelling shows a specific case study and, being ore- and mineralization specific, will vary from application to application.

Table II-Mining parameter summary

Unit	Width (cm)	Density	Grade (In-situ)	Tonnage Split	Cut, grade, PGM g/t	Description	tpm	Mining Method
LC	10	3.90	2.05	0.39	175 cm @ 3.66 t/m3 @ 2.93 g/t 4e	Full Cut	250,000	Mechanised
HWPX	30	3.25	0.30	0.98				
UG2A	30	3.80	3.15	1.14	135 cm @ 3.73 t/m3 @ 3.51 g/t 4e	LC Under-cut	196,659	Conventional
MPX	25	3.25	0.20	0.81				
UG2B	70	4.00	4.95	2.80	80 cm @ 3.85 t/m3 @ 4.51 g/t 4e	Full Under-cut	120,360	Not Practical
FWPX	10	2.80	0.10	0.28				

Based on the above 250 kt/month (mechanized mining) *versus* 200 kt/month (conventional mining) trade-off, the differential cash flow results are shown in Figure 13. The cash flow analysis is very dependent on the grade of the top seams that are recovered as a result of the wider mining cut.

View scenarios below with reference to Figure 6.

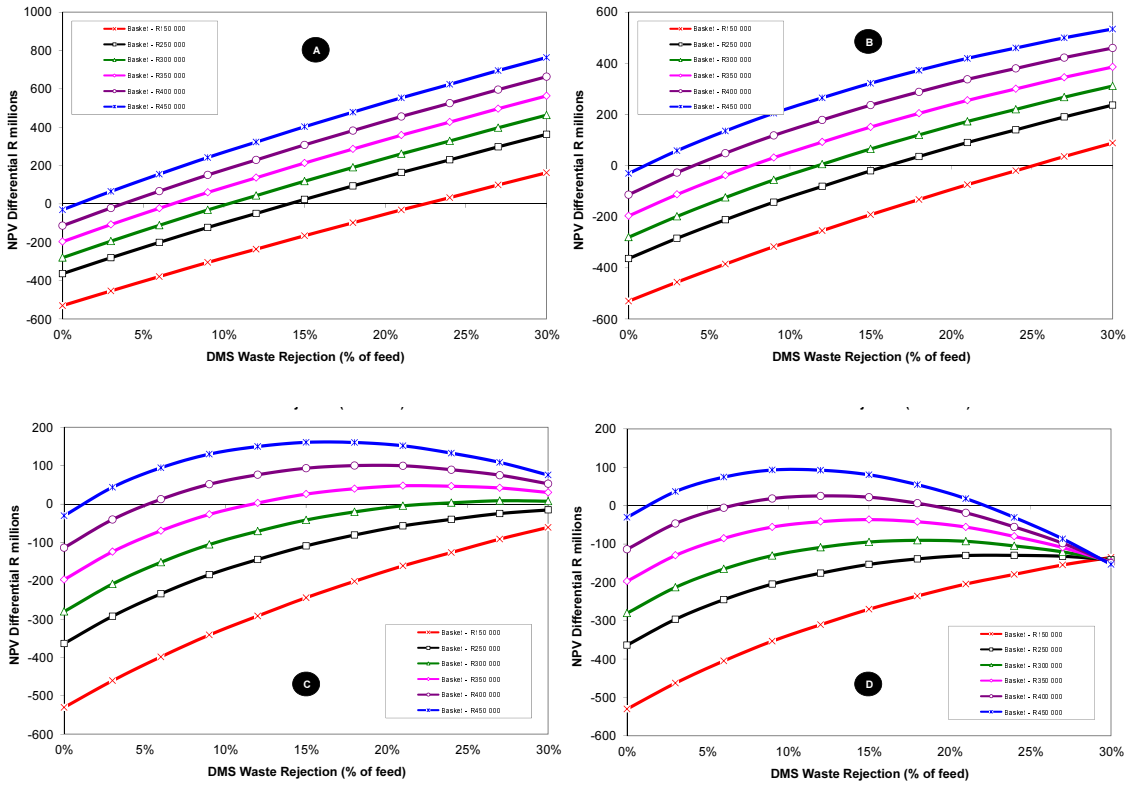


Figure 13-Differential NPV analysis for various DMS rejection rates, rejection efficiencies, and metal prices. Comparing a mechanised (with DMS) conventional operation (no DMS)

The results from the modelling exercise show different outcomes as the DMS efficiency, rejection, and metal prices forecasts are varied. In this situation, the mechanized (DMS approach) is improved for higher metal prices and plant feed grades. The rejection cut-off is also very dependent on the metal price.

The use of DMS in this situation provides the mine management with a valuable tool for reacting to metal prices. For an efficient DMS operation, the project value-add is significant, especially when operating in an environment of high metal prices.

Summary and conclusions

DMS is a proven technology choice that allows for efficient preconcentration ahead of milling and flotation in platinum processing. DMS is a robust solution that can be tailored to a range of both greenfield projects and brownfield expansion projects. Numerous benefits are provided by implementing the technology, including:

- Significant project value-add through a reduction in the overall operating and capital cost expenditures
- Up to 30 per cent power reduction and 15 per cent water savings, should a good rejection rate be targeted
- DMS implementation is particularly suited to low-grade deposits or in a bear market. As was shown in Scenario 1, DMS adds significant project value when metal prices or plant feed grade are low
- The use of a DMS allows mining operations to target a wider cut and lower cut-off grade. Additional metal is processed through the plant without incurring the processing costs for treating additional waste material
- the tailings storage facility footprint can be reduced, limiting the impact on the environment.

References

1. Holloway, A.R., Jones, L., and Lawrence, S.R. Pre-concentration of platinum group and base metal ores by dense medium separation. *Advances in Mineral Processing Science and Technology*. Gomez, C.O., Nesset, J.E., and Rao, S.R. The Metallurgical Society of CIM, 2009. pp. 373–382.:
2. Cresswell, M. A selected review of DMS application and engineering design practice. DMS Powders 9th Technical Dense Medium Symposium.

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