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A Holistic Approach to Optimise Process Water Retention and Residue Disposal for Orapa Mines

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1 INTRODUCTION

Orapa Mine is situated 240 km west of Francistown, in Botswana's arid central district. Water is a scarce non-renewable resource. It is currently supplied from an aquifer system around the mines that has negligible recharge. A combination of unfavourable factors including low rainfall, high evaporation rates and a flat topography contribute to this situation. Debswana is exploring various options to significantly reduce water consumption over the life of the mines.

The Orapa mines are currently operating at an average raw water consumption of 0.5 m^3/t of head feed for all the four treatment plants at Orapa, Letlhakane and Damtshaa. In order to extend the life of the existing aquifer, Orapa has an objective to reduce raw water consumption by 50% within the next decade. This will have the desired effect of increasing aquifer longevity at current consumption.

However, Orapa is planning to replace one of its older plants with a new generation plant and will also build a dump treatment plant at Letlhakane Mine. These plants are likely to use more water as they will be designed to produce a finer product to enhance liberation of diamonds.

Orapa Number No. 2 Plant, the newest treatment plant at Orapa uses high rate thickeners (Ultraseps) and consumes over 0.8 m^3/t of raw water per head feed tonnage. The current disposal method comprises the pumping of combined thickened material to a slurry dam using cyclones for wall building. The mine is considering alternatives for future dewatering and disposal systems with a view to minimising water consumption, capital/operating costs and environmental impacts.

The mine has investigated a number of options for future final residue dewatering and disposal. These include dewatering using conventional, high rate and paste thickeners with the associated disposal options.

This study covers the complete supply chain from water supply, thickening, transportation and disposal including environmental and rehabilitation considerations. The study concludes that paste thickening of slimes only is not only more cost effective but also offers a known and tested technology solution. This paper presents the following aspects of the study:

(i) Description of the various options investigated.

(ii) Capital and operating cost comparison for each option, including net present cost (NPC) analysis.

2 DISPOSAL ALTERNATIVES

2.1 Conventional slimes

The Orapa No. 1 Plant utilises a conventional disposal system, so named because it makes use of large diameter conventional thickeners. These thickeners do not operate reliably if grits are present in the feed, so the grits are removed using cyclones, de-watered using screens and then disposed separately by conveyor system. The thickened slimes produced by the thickeners typically have low densities (1.20 – 1.30 t/m^3) and a low yield stress (< 25 Pa). This material can be pumped with a centrifugal pumping system without excessive head and efficiency de-ratings. The slimes are pumped to containment dams, where it is normally disposed of from multiple open-ended pipes around the perimeter walls. The dams must be constructed entirely from borrow material (tailings or imported gravel). Waste rock is typically too coarse to contain the slimes unless finer material is selected for the upstream face.

2.2 Co-thickened slurry

Co-thickened slurry disposal is the current disposal method at Orapa No. 2 Plant. The slimes and grits are not separated prior to thickening, and are fed to high rate thickeners. The material in the density range of 1.25 – 1.40 t/m^3 can be produced, with typical yield stresses less than 50 Pa. The thickened slurry is pumped to slurry dams for disposal. The slurry is cycloned at the dam, with the coarse grits underflow being used for constructing the walls of the slurry dam. The cyclone overflow is discharged into the middle of the dam.

The current operation does not achieve the optimum performance that could be attained by a co-thickened slurry system. This is largely due to poor thickener performance due to overloading. The performance can therefore be improved and the results for a co-thickened system reflect that which could be achieved with an optimum system.

2.3 Slimes paste

This paste alternative has examined the option of separating the slurry into slimes and grits fractions before thickening. The grits portion is dewatered on screens, before being transported to a dump site using conveyors. The slimes fraction is fed to paste thickeners, with the underflow produced being a high density (1.35 – 1.45 t/m^3) and high yield stress (100 – 200 Pa fully sheared) material as shown in Figure 1. Due to the high pressures required to pump this material, piston diaphragm positive displacement pumps have been considered.

A number of disposal sites were considered, including a central discharge system, a waste rock impoundments dam and discharging off the side of the existing tailings dump. For the study, the option of discharging off the side of the tailings dump was selected as the most appropriate for the mine.

Figure 1 Slimes paste (approximately 132 Pa yield stress)

2.4 Co-thickened paste

Paste can also be produced from the full tailings stream, without removing the grits, as is the case at De Beers' Combined Treatment Plant in Kimberley. The paste produced with have similar yield stresses to the slimes only paste system, but the densities are expected to be higher (1.50 – 1.60 t/m^3).

For the co-thickened paste piston diaphragm pumps were considered and the disposal site for the paste was off the side of the tailings dump.

2.5 Other alternatives

The study also investigated other options which are not detailed in this paper:

- A conveyor option was investigated to examine the potential reduction in disposal costs assuming a conveyable product. The cost savings look attractive; however, there is no current technology available that can be used to produce a conveyable material for kimberlite.
- The study investigated locating the thickeners either at the plant or close to the disposal site. Locating the thickeners at the plant is more cost effective and so this option is presented in the paper.

3 TECHNICAL CONSIDERATIONS

3.1 Water availability

Orapa Mine is projected to use up to 22 million cubic metres of water per annum by 2012, when the new plant at Orapa and the Letlhakane dump treatment plants are commissioned. This increase is not sustainable as the groundwater sources are currently being mined due to low rates of natural recharge. This is mainly due to adverse climatic and topographic conditions in the country. Improved water retention technology is therefore a necessity for Orapa mines.

3.2 Dewatering

With improvements in thickener and flocculant technologies it has become possible to produce higher density and viscosity material than previously achievable. The flocculant dosage rate must be considered along with the thickener, as the operating costs associated with the flocculant are significant over the life of mine.

There is, however, a limit to what can be achieved through thickener technologies. With the increase in density there is also an increase in rheology. Once the kimberlite material is in the paste range (fully sheared yield stress greater than 100 Pa) a small change in density has a significant effect on the rheology. Once this range is reached, the benefit of increased water saving through increased density must be balanced against the increased pumping cost.

3.3 Transport

Two transport methods have been utilised in this study; pipelines and conveyors. For pipeline transport the main factors which must be considered are the settling velocity and the pipeline pressure. The minimum transport velocity for grits material was based on measured data for low density slurries. For high density materials, the pipeline pressure gradient was maintained high order to prevent the build up of material due to laminar flow settling.

3.4 Disposal

A full range of disposal methods and types for the slimes and grits was considered in the trade-off study to ensure that current and conventional methods were compared to future “drier” methods. In the cases where slimes and grits were separately disposed, the grits reported to a grits dump by means of conveyors. Table 1 summarises the deposition systems.

Due to existing pump and pipeline infrastructure, alternative disposal sites and methods for the slurry and conventional slimes disposal facilities were not considered. However for paste, new infrastructure provided the opportunity to evaluate three disposal methods and two sites.

The conventional slimes disposal systems were found not only to be expensive due to wall building but also poor in terms of water consumption.

The slurry disposal system was found to be cost-effective, with good water recovery, but relied heavily on good operation of the dewatering circuit.

Table 1 Disposal systems

Case	Deposition and containment method	Water recovery system
Conventional slimes disposal	Build five new impoundment dams with walls 35 m high and raised incrementally centreline. Open-ended deposition. Cycle deposition between dams. (Dry density = 1.10 t/m^3)	Central penstocks gravitating to plants or new return water dams
Co-thickened slurry disposal	Continue with current slurry dam building = Cycloned deposition - underflow for wall building and containment of overflow. Total of 4 dams to 50 m elevation with rock buttressing. (Dry density: wall = 1.50; basin = 0.75 t/m^3)	Central penstock systems gravitating to plants for existing dams and gravitating to return water dam for new dams
Slimes paste disposal	1. Central discharge from two towers located on corners of existing slurry dams -of 42 m. Paste flows across landscape and on top of slurry. Some boundary walls required to protect existing infrastructure. (= 1.40 t/m^3)	Stormwater system of trenches and collection sumps and pumps
	2. Side-hill discharge from northern edge of existing tailings dump (45 m high). Paste flows across old slimes dams initially, then across landscape. Boundary walls of waste rock required to prevent flow towards open pit	Stormwater system of trenches and collection sumps and pumps
	3. Impoundment of paste by waste rock stripped from open pit. Walls formed around perimeter of old slimes dams. Paste deposited from edge of tailings dump and perimeter walls (45 m high)	Stormwater controlled in north east corner and pumped off for re-use
Co-thickened paste disposal	As for slimes paste disposal except slightly larger capacity required to cater for grits. (Dry density = 1.60 t/m^3)	
"Dry" conveyed slimes disposal	"Dry" slimes conveyed to northern edge of existing tailings dump (45 m high). Face advancing conveyor stacker system to side-hill discharge across old slimes dams initially, then across landscape. Boundary walls of waste rock required to prevent flow towards open pit. (Dry density = 1.40 t/m^3)	Stormwater system of trenches and collection sumps and pumps

The paste disposal systems were found to be capital intensive but more efficient in terms of water conservation and operating costs. The side-hill and impoundment methods had the advantage of depositing on top of an old slimes dam site and would reduce closure costs. The central discharge site covered some existing infrastructure, all of which could be relocated, but had more limited capacity for future expansion of the site than the other two.

3.5 Rehabilitation

Conceptual rehabilitation plans were developed for all of the disposal systems. The costs were estimated to ensure that the life cycle costs of all the systems were fairly evaluated. The rehabilitation plans were based on the following principles:

- Topsoil stripping and stockpiling for re-use.

- Progressive rehabilitation to take place where possible.
- All slopes must be water and wind erosion resistant for long term sustainability.
- All beach areas or shallow slopes to be terraced, contoured or paddocked to control or contain run-off and to be covered with topsoil and revegetated.
- Waste rock walls or walls clad with waste rock would not be flattened but rather left steep and lightly covered with soil for natural vegetation establishment.

The central and side-hill paste disposal options resulted in very large rehabilitation areas, probably leading to a topsoil deficit. Since the topsoil is largely fine grained, it was planned to add calcrete gravel to the topsoil to improve run-off erosion resistance. The calcrete is readily available around the mine.

4 CASE COMPARISON

The cases were compared taking into consideration the capital, operating and rehabilitation costs over the life of mine (2028). The rehabilitation costs that will only occur after the mine closure have been included in the costing.

4.1 Water consumption

The cost of water has a significant effect on the overall cost analysis. It constitutes up to 21% of the total operating cost over the life of mine for some options. The water infrastructure required is also a large capital cost for the mine. Figure 2 below shows the water consumption for the options considered.

The current operation does not achieve the optimum water saving that could be achieved by a co-thickened slurry disposal system. This is largely due to insufficient thickening capacity, resulting in low underflow densities. There is scope to improve the operation of the plant by increasing the thickening capacity.

Implementing a conventional system will result in no change in the water consumption. The only option that is likely to achieve the target water saving of 50% is the conveyor option, however, the technology required to achieve this has not been fully developed.

Optimising the slurry disposal system has the potential to achieve significant water savings. However, the reduction in water required is not great enough that sufficient water can be obtained from local well fields, and water from external sources will be required. For the paste and conveyor options, sufficient water should be available if local well fields are fully developed.

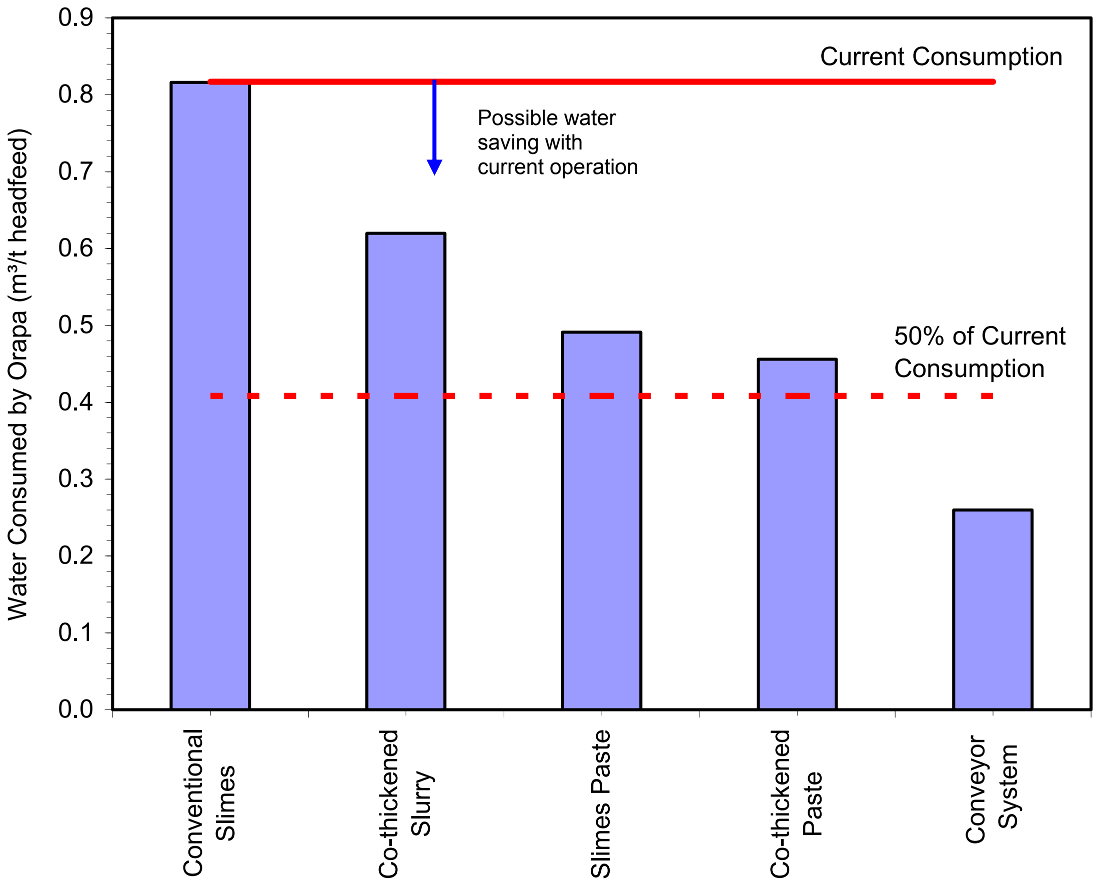

Figure 2 **Water consumption for the disposal options considered**

4.2 Cost comparison

4.2.1 Capital costs

Figure 3 presents the breakdown of the capital costs for each option. The most significant capital cost for all the options is the water infrastructure cost. For the conventional slimes system (and for the current operation with the slurry system) over one billion Pula (US$ 1 = P 5.52) must be invested over the life of mine to have sufficient water to continue production. This is greater than the total cost of either of the paste systems.

Other significant capital costs are the earthworks, especially for the conventional slimes system, where containment dams must be constructed, thickeners and mechanical equipment.

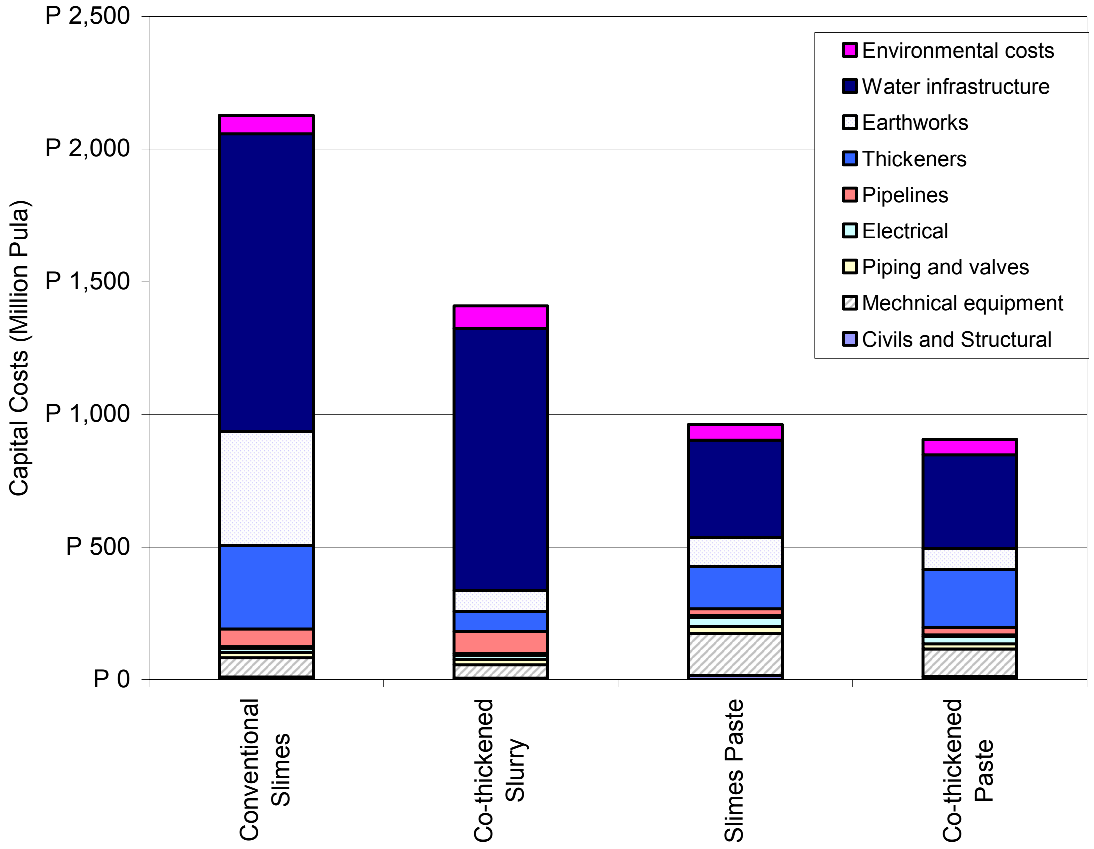

Figure 3 **Capital costs**

4.2.2 Net present costs

A net present cost (NPC) analysis has been carried out, utilising the total capital expenditure and the operating costs for the life of mine. Rehabilitation and closure costs have also been included. The costs are shown in Figure 4.

4.3 Discussion

Including the water infrastructure costs into the analysis significantly alters the results. Figure 5 below shows the NPC of the options considered with and without the water infrastructure costs. The optimum operating position is completely different. Without looking at the cost of supplying water to the mine, it appears that producing co-thickened slurry will be the most economical alternative. Once the water infrastructure cost are included, it becomes clear that the water consumption must be reduced as far as possible to achieve a maximum cost saving.

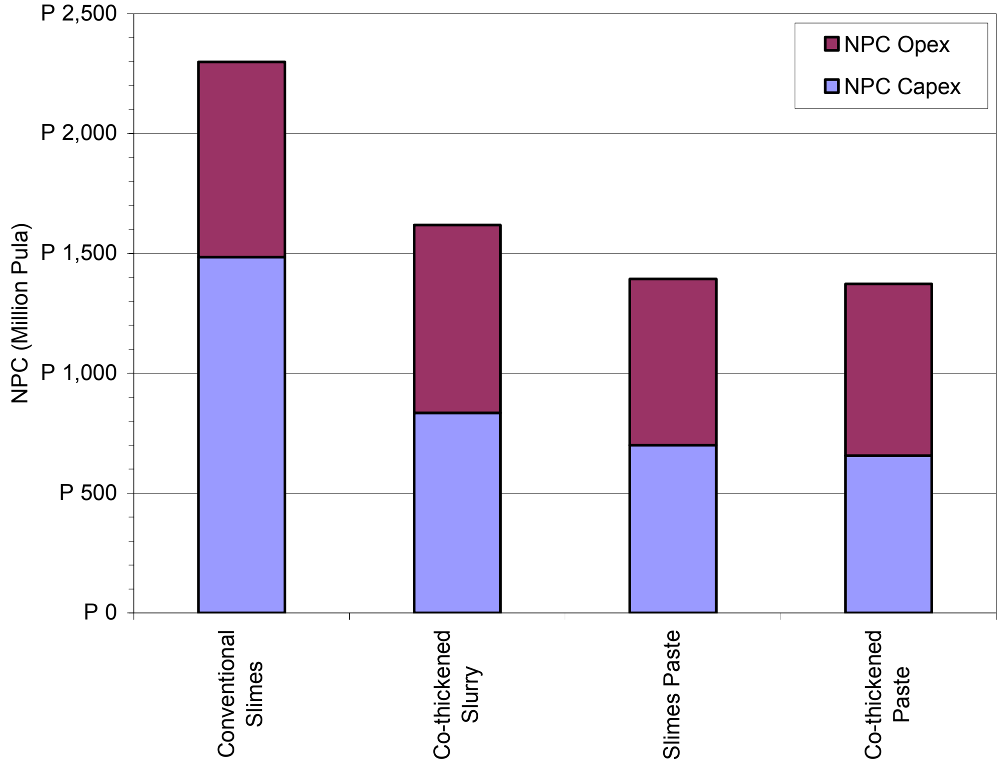

Figure 4 Net present costs

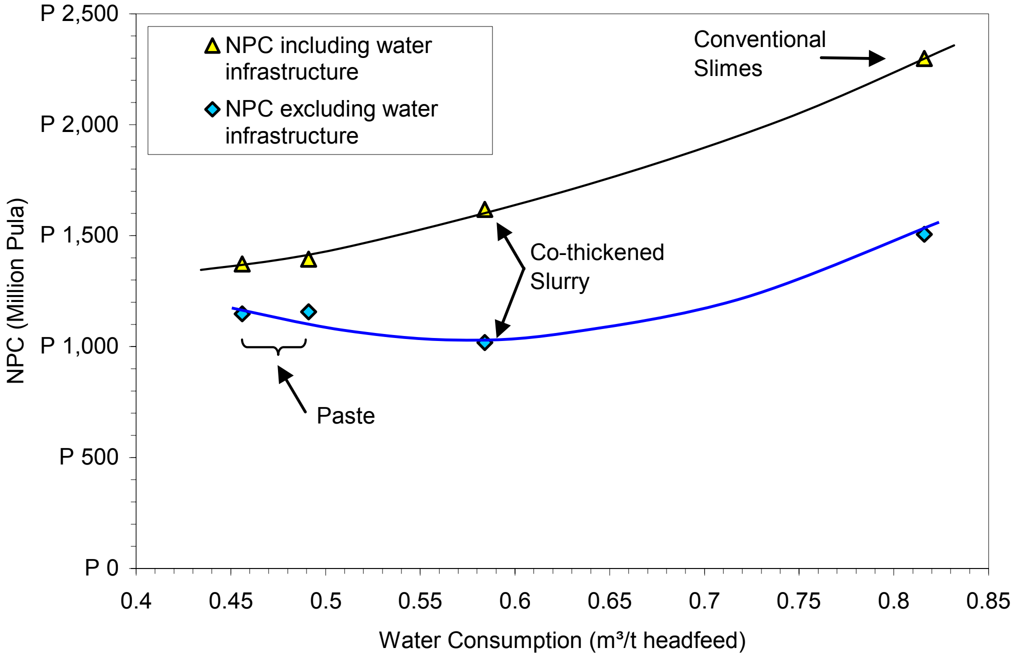

Figure 5 Net present cost compared with water consumption

4.4 Risk assessment

There is some risk associated with these options that must also be considered when evaluating these results. In general, the risk increases as the water consumption decreases.

Both the conventional slimes and the co-thickened slurry systems are currently in use by Debswana, and consequently have a low risk associated with them. While the technology to produce and dispose of paste is available, the assumed densities and water recovery values have not been verified. If the paste produced has a significantly higher viscosity at the target density, it will increase the pumping cost. Orapa is currently installing a pilot paste thickener to determine the characteristics of the paste that can be produced by paste thickeners.

The other significant risk to be considered is the possibility of running out of water, if significant reduction in water cannot be realised. This would have an even greater damaging and unacceptable impact on production and revenue.

5 CONCLUSIONS

The conclusion from this study is that paste thickening offers the most cost effective solution for the Orapa Mine water challenges. The benefits must however still be confirmed and Debswana has initiated a prototype paste thickening project that will confirm the water savings together with the transportation and disposal costs and challenges.

The other significant conclusion drawn from this study is that complete costs of mine water supply chain must be considered when assessing the most economic thickening, transportation and disposal option. Possible revenue loss and associated risks of any given option must also be considered.

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