A Water Recovery Comparison of Two Kimberlite Paste Systems

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ABSTRACT

The erratic nature of rainfall and hence raw water availability in Southern Africa has spurred the diamond mining industry to modify metallurgical operations so that raw water consumption is minimised. These modifications include the incorporation of "paste" thickeners within the water recovery circuits as well as a review of the metallurgical processes within these circuits.

This paper presents a case study comparison of the water recovery efficiency of two paste installations within the diamond mining industry in Southern Africa – one in which a fine tailings product is thickened following a de-gritting step, and one in which the de-gritting step has been omitted and a coarser tailings product is thickened.

1 KIMBERLITE — ORE PROCESSING AND WATER RECOVERY

Kimberlite, unlike metaliferous ores, is a unique rock of volcanic origin which is host to diamonds and other xenoliths. Originally, thought to be formed from subducted mantle material, molten magma is now thought to have intruded the earth's crust from depths of 150 km to 300 km to erupt onto the surface as an explosive pyroclastic volcano. After cooling, a modified rock is thought to have formed as a result of substantial hydrochemical alteration either during or post placement. This rock or kimberlite is best described as follows (Kirkley et al., 1991):

> *"a hybrid rock, comprising fragments of high temperature megacrysts (large crystals) which have reacted with a relatively low temperature, volatile (containing readily vaporisable gases) matrix (a fine particulate groundmass), and during and after intrusion with high-level groundwater becomes studded with country wall rock."*

Evidence, has shown that the cementing matrix is composed of a range of clay minerals, of which those from the smectite group are dominant, comprising anywhere from 30% to 90% of the clay mineral (-2 μm) fraction.

Every economically viable kimberlite deposit contains a unique diamond size distribution which is specific to the deposit. Consequently, the main objective of the metallurgical plant is to comminute the ore to maximise release (or liberation) of the diamonds contained therein, while simultaneously preventing damage to the larger diamonds. Once this has been accomplished the ore is washed and screened for preparation for the subsequent diamond concentration and recovery stages.

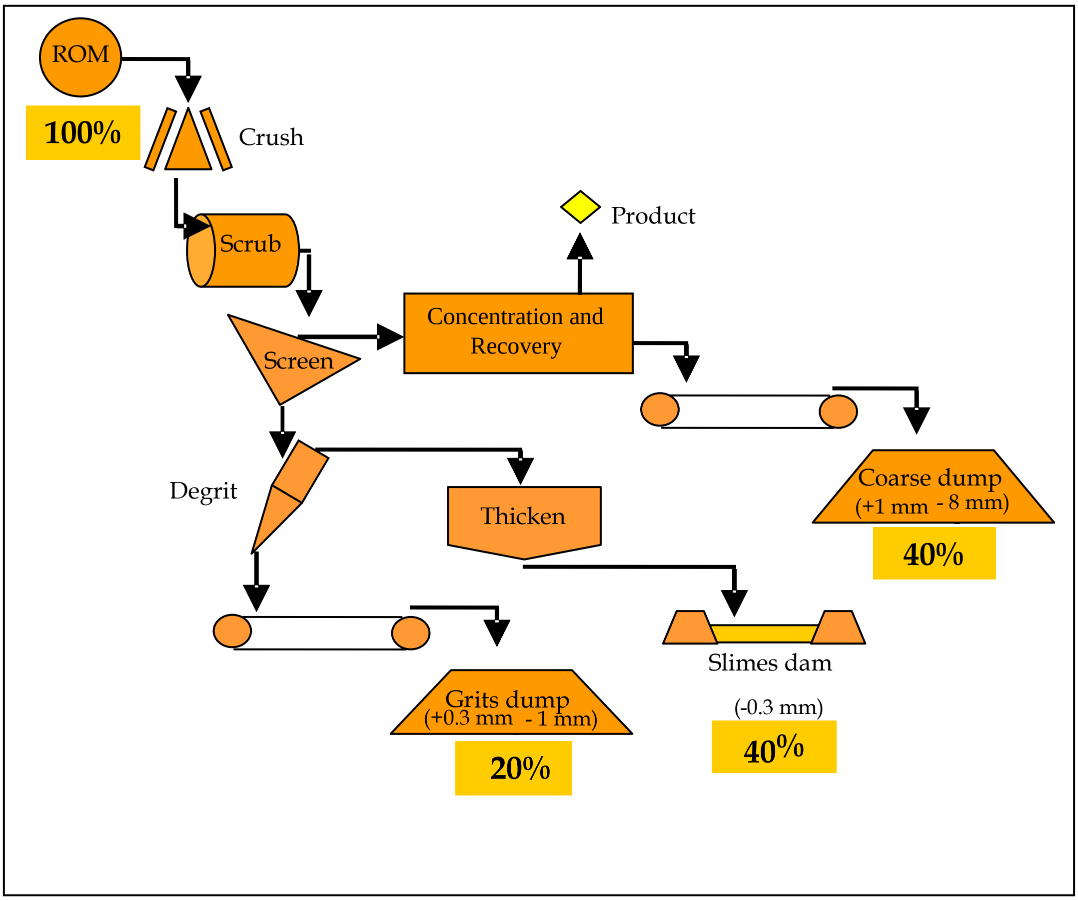

Figure 1 **Solids process flow through a conventional diamond metallurgical plant**

Following primary crushing, the ore undergoes a washing and dis-agglomeration step in which it is tumbled together with plant process water in a variation of a simple overflow discharge mill known as a scrubber. The scrubbing process is designed to remove the clay groundmass matrix from the harder and denser kimberlite components since the wet clays are responsible for significant problems in crushers, screens, chutes, bins, transfer points, and conveyors, not to mention subsequent concentration steps. Scrubbing represents a critical point of departure in determining the future behavioural characteristics of the fine tailings product since it marks the first contact between the kimberlitic clay matrix component of the ore and the plant process water. The chemical quality of the process water has a significant bearing on the colloidal properties of the resulting clay slurry and hence on the behavioural characteristics of the tailings product.

The scrubbed ore is discharged from the scrubber and is directed to the subsequent screening stage at which point it is split into a number of size fractions:

- +8 mm: This stream represents the "oversize" material which is returned to the secondary crusher for re-crushing.
- -8 mm + 1 mm[1]: This stream represents the "correct sized" material and is directed to the concentration circuit. Barren concentrate tailings report to a tailings dump at a moisture content in the order of 18% by mass.
- -1 mm slurry: This stream represents the "bottom cut-off sized" material and is directed to the water recovery and tailings disposal circuit.

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[1] The bottom cut-off size may vary from mine to mine but is typically in the range -1.6 mm to -1 mm

Since conventional thickeners are employed within the water recovery circuits of most plants, a further sizing step using de-sanding cyclones is used to remove the coarser “grits” fraction from the thickener feed, consequently two further tailings streams are generated:

- A +300 µm grits stream which is further dewatered over vibratory screens and discharged by conveyor to a grits dump at a moisture content in the order of 20% by mass.
- A -300 µm fines stream which is further dewatered in the conventional thickeners – thickened underflow is generally pumped to an impoundment dam using centrifugal pumps.

The advent of more advanced thickening processes such as Paste thickeners has resulted in a re-evaluation of the need for a de-gritting step, since it represents a substantial capital and operating investment. The question therefore posed is “does de-gritting save water or not?”

The present case study compares two diamond Paste water recovery circuits (one incorporating a de-gritting step and one without a de-gritting step) on the basis of raw water consumption (m^3/ton of head feed treated).

2 KIMBERLITE PASTE CASE STUDY

Two Paste thickener plants are currently installed in two different diamond mining operations in Southern Africa. The first installation includes five 15 m diameter Paste thickeners at the De Beers Combined Treatment Plant (CTP) in Kimberley South Africa. The second installation is a 16 m diameter prototype Paste thickener at Debswana’s Orapa Mine in Botswana. The water recovery achieved at this test unit was applied to the water balance calculations for Orapa Mine.

2.1 Tailings Properties

Figure 2 and Table 1 show the difference in particle size distribution for the thickener feed streams of the two paste systems. The total particle size distribution for the Orapa system before de-gritting, was included for comparison.

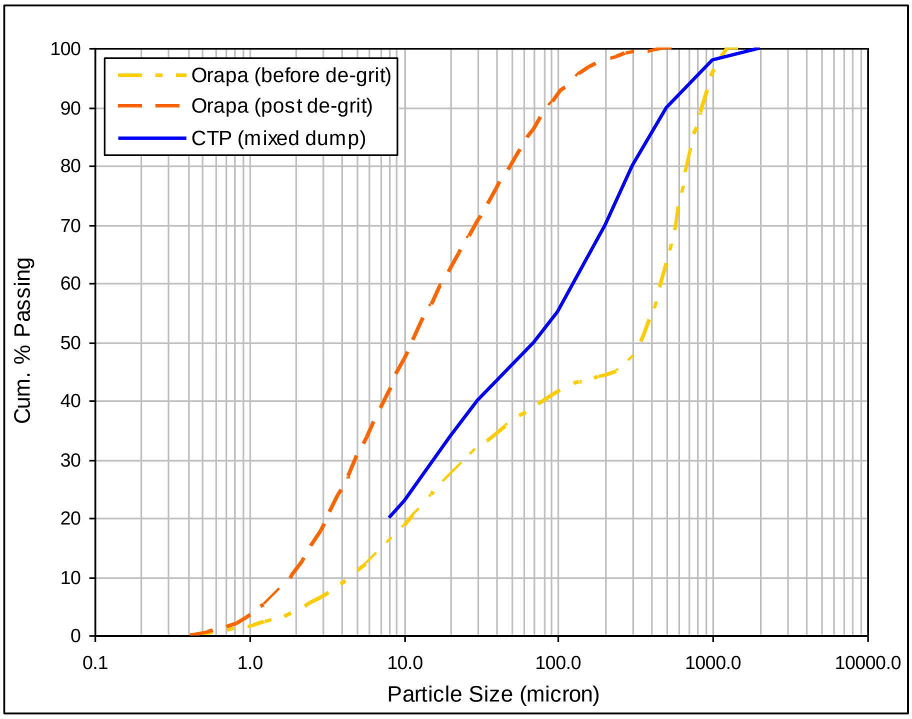


Figure 2 **Particle size distribution**

Table 1 **d_{50} particle size**

Operation	D_{50} Particle Size (µm)
Orapa (before de-grit)	363
Orapa (post de-grit)	12
CTP	70

Table 2 and Figure 3 present the characteristics of the clay fraction (-2 µm) within each of the tailings streams. In both cases, the clay fractions are dominated by smectite clay minerals. The clays within the CTP tailings appear to be highly sodium ion exchanged (high ESP value).

In terms of slurry behaviour, these properties when plotted on a smectite behavioural map show that the clays within the CTP tailings fall into the non-interactive zone indicating that the tailings are dispersive or difficult to flocculate at low solids concentrations and that upon thickening high yield strength would be achieved gradually.

The Orapa tailings are more interactive (moderate ESP value) indicating that the tailings would flocculate easily but that on thickening high yield strength would be achieved rapidly.

Table 2 **Kimberlite clay characteristics**

Operation	Smectite Clay Content (%)	ESP (%)	Slurry pH
Orapa	88	18	8.4
CTP	60	69	8.7

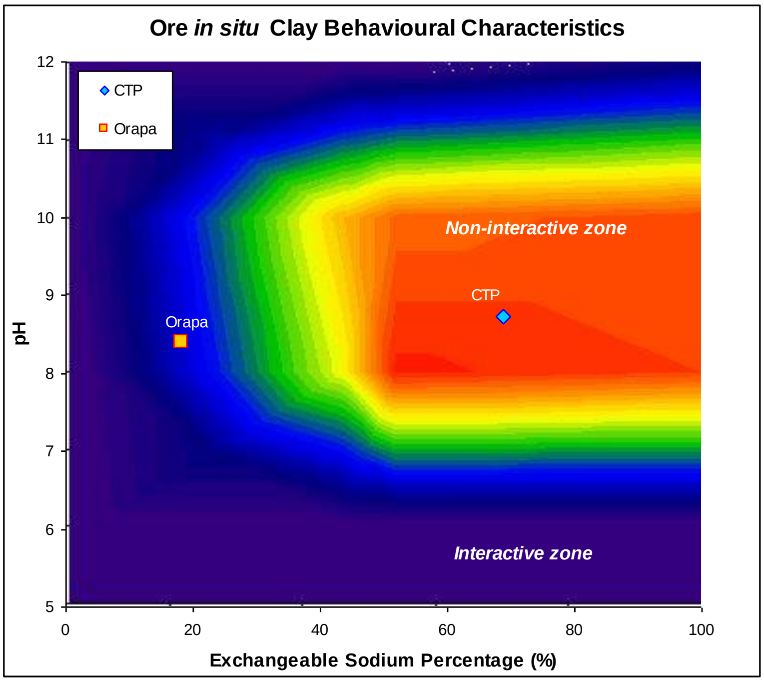


Figure 3 **Smectite clay behavioural characteristics**

Figure 4 presents typical sheared thickener underflow yield stress correlations for both systems.

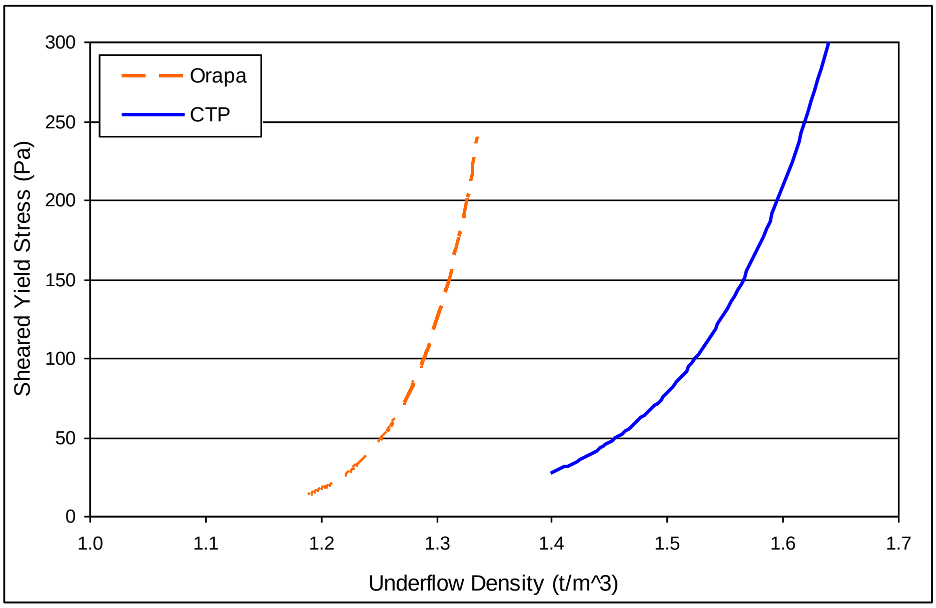


Figure 4 Sheared thickener underflow yield strength curves

2.2 Process Balances

The water balances of both process systems are summarised in Figure 5 and Figure 6 – in both cases, no water is recovered from the deposition site at the underflow densities delivered to site:

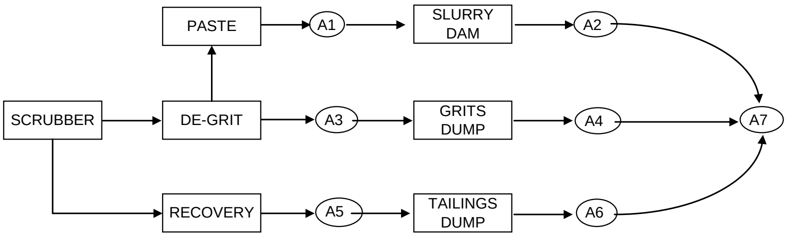
Paste Plant Orapa

Input parametes

Water density (t/m3)	1.00
Solids density (t/m3)	2.55
Head feed (t/h)	1400
Bottom cut-off fraction (% of head feed)	57%
-300 micron fracion (% of bottom cut-off)	65%
Underflow density (t/m3)	1.3
Underflow solids conc (%v)	19.35
Tailing moisture content (% m)	15%
Grits moisture content (% m)	18%

Output

Raw water consumption	0.72



STREAM NUMBER	A1	A2	A3	A4	A5	A6	A7
STREAM DESCRIPTION	*Paste underflow to dam*	*Water lost to dam*	*Grits to dump*	*Water lost to dump*	*Tailings to dump*	*Water lost to dump*	*Total water lost*
SOLIDS MASS (t/h)	519	-	279	-	596	-	-
WATER VOLUME (m3/h)	847	847	61	61	105	105	1014
SLURRY VOLUME (m3/h)	1051	-	-	-	-	-	-
SLURRY DENSITY (t/m3)	1.3	-	-	-	-	-	-
MASS CONCENTRATION (%)	38.0%	-	82.0%	-	85.0%	-	-

Figure 5 Water balance for the orapa paste thickener system

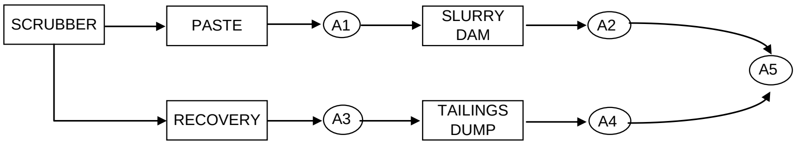
CTP Plant

Input parametes

Water density (t/m3)	1.00
Solids density (t/m3)	2.75
Head feed (t/h)	800
Bottom cut-off fraction (% of head feed)	55%
Underflow density (t/m3)	1.52
Underflow solids conc (%v)	29.71
Tailing moisture content (% m/m)	15%

Output

Raw water consumption	0.55



STREAM NUMBER	A1	A2	A3	A4	A5
STREAM DESCRIPTION	*Paste underflow to dam*	*Water lost to dam*	*Tailings to dump*	*Water lost to dump*	*Total water lost*
SOLIDS MASS (t/h)	440	-	356	-	-
WATER VOLUME (m3/h)	379	379	63	63	441
SLURRY VOLUME (m3/h)	539	-	-	-	-
SLURRY DENSITY (t/m3)	1.52	-	-	-	-
MASS CONCENTRATION (%)	53.8%	-	85.0%	-	-

Figure 6 Water Balance for the CTP Paste Thickener System

The theoretical raw water consumption curves for each system as well as the operating point for each Paste thickener are plotted in Figure 7.

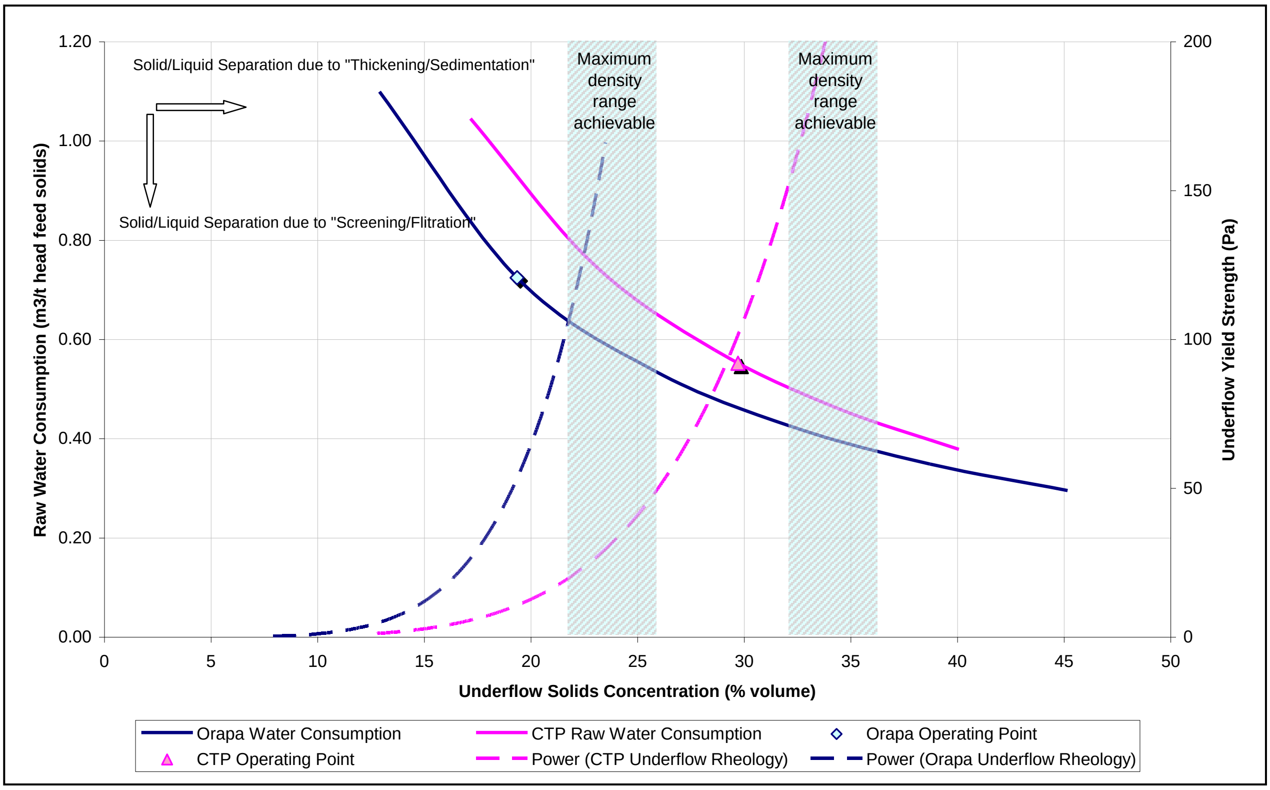


Figure 7 Raw water consumption curves for the orapa and CTP paste systems

A comparison of the two paste systems indicates that at their current operating conditions, the system operated without a de-gritting step achieves a 24% reduction in raw water consumption (at 0.55 m^3/ton of head feed solids) when compared with the system in which a de-gritting step has been included (at 0.72 m^3/ton of head feed solids).

A closer inspection of the system curves clearly illustrates that raw water consumption is influenced by two solid/liquid separation components:

- *A de-gritting and "screening/filtration" component:* A significant step-change in water savings appears to be achieved by removing and dewatering the coarser fraction of the thickener feed through a de-gritting and filtration step. The magnitude of the savings depends on variables such as:
    - The de-gritting cut-point size.
    - The ratio of coarse to fines in the feed.
    - The residual moisture content of the filtered coarse product.
- *A "thickening/sedimentation" component:* A significant but diminishing water savings appears to be achieved by thickening the remaining non-filterable component of the feed (containing the fine and clay solids). The magnitude of the savings depends on:
    - The density of the paste thickener underflow.
    - The slurry chemistry characteristics.

The above conclusion would lead one to presume that to minimise raw water consumption (maximise water saving), one should de-grit to the smallest particle size as possible (in order to filter the maximum tailings volume as possible) and then to thicken the remaining fines portion to as high a density as possible. This is indeed possible, but the rheology of the thickened fines fraction will place limits on the maximum underflow density which is achievable from a thickening unit (i.e. the maximum thickener operating point). The finer the size distribution in the thickener feed, the lower the density at which maximum yield strength is achieved.

In the current case study, the water savings achieved at Orapa through the de-gritting step are off-set by the higher densities achieved in the paste thickener at the CTP. This is reflected in an analysis of the water recovery efficiencies of each solid/liquid separation step from both systems which indicates that de-gritting prior to thickening may reduce the water of the thickening process as a result of the finer size distribution of the feed (Table 3).

Table 3 Water recovery efficiency

Solid/Liquid Separation Process	**Orapa (%)**	**CTP**
Screening/Filtration (de-grit)	59.5	
Thickening/Sedimentation	71.8	85.5
Overall System	79.8	85.5

3 CONCLUSION

The water recovery efficiency of two paste installations within the diamond mining industry in Southern Africa was compared. In one system a fine tailings product following a de-gritting step is thickened, and in the other the de-gritting step has been omitted and a coarser combined tailings product is thickened. An analysis of the water recovery efficiency of the systems indicates that although a de-gritting step recovers a significant amount of water before the thickening process, the finer feed to the thickening unit may reduce the consolidation characteristics of the material and therefore reduce the efficiency of the thickening unit.

Other issues which may sway the argument in favour of including a de-gritting step in the circuit include the following:

- The reluctance to "co-thicken" the grits with the fines since they may have a potential resource value.
- The ease of system operation when the grits fraction has been removed (i.e. reductions in system blockages and downtime).

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