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Rheomax™ and Water Conservation at Orapa Mine

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Abstract

The Debswana Diamond Company's water and residue strategy is aimed at reducing mine water consumption by 50% by 2008. Paste thickening of the tailings has contributed significantly to this goal, however, recent studies have indicated that a novel flocculant product (CIBA™ Rheomax™ ETD) may release significant amounts for water from the thickened tailings.

The use of Rheomax™ ETD in two applications i.e. dosing prior to deposition at the disposal site and prior to a filtration step were assessed and the water savings and cost implications were compared to that achieved by conventional; high rate and paste thickening systems.

1 Introduction

The Debswana Diamond Company's water and residue strategy is aimed at reducing mine water consumption by 50% by 2008 while achieving a cost effective integrated residue disposal system for Debswana's diamond mines located in Botswana. Paste thickening of fine tailings has the potential to significantly contribute to this goal. The prototype production paste thickener has demonstrated that on average a 28% water consumption reduction is possible with a paste thickening system.

During the last two years, CIBA® has introduced a novel polymer flocculant range (CIBA® Rheomax™ products), which are reputed to have superior properties to conventional polyacrylamide flocculants. One of the claims is the potential release of significant amounts of additional water from the pre-thickened tailings. Two possible system application configurations were identified for testing at Debswana:

- Disposal site system application: Pumping thickened tailings to the disposal site and then treating with the Rheomax™ ETD flocculant to maximise water recovery from the disposal site.
- Filtration system application: Treating thickened tailings with Rheomax™ ETD flocculant prior to filtration at the plant area. The filter cake would then be transported by conveyor to the disposal site.

This paper reviews test work conducted at Orapa mine in comparing the water recovery potential and system costs for Rheomax™ ETD dosing for these two system configurations against three thickening only baseline systems.

2 Potential water savings benefits

Kimberlite, unlike metaliferous ores, is a unique rock of volcanic origin which is host to diamonds and other xenoliths. Up to 20% of the mineral component of the kimberlite ore may consist of clay minerals of which those from the smectite group can comprise anywhere from 30 to 90% of the clay mineral (-2μm) fraction.

During metallurgical processing, the ore is crushed and scrubbed to remove the fines fraction before diamond recovery. The "bottom cut-off sized" tailings material (typically -1.6 mm) is directed to the water recovery circuit where de-sanding cyclones are used to separate the coarser "grits" fraction (typically -1.6 mm to +300 μm) from the thickener feed (-300 μm).

The advent of more advanced thickening processes such as paste thickeners has resulted in an improvement in the recovery of water from the fines stream; however, the resultant thickened tailings still contain water contents in the order of 64% by mass as a general rule for kimberlite tailings at the time of their disposal. There remains therefore significant potential for recovering water from the tailings after thickening.

Observations of the thickened fine tailings at densities in excess of 1.3 kg/l have shown conclusively that no bleed water is evident from the toe of the deposit and that the contained water content appears to be locked up within the tailings particle matrix. Scanning electron microscope studies (Vietti, 2004) of thickened kimberlitic tailings have demonstrated the so-called “house of cards” orientation of the clay particles which impart an internal spongy pore structure to the tailings in which the water is trapped (Figure 1). Release of the locked water from the tailings will therefore require a re-orientation of the clay particles such that the internal pore water is released.

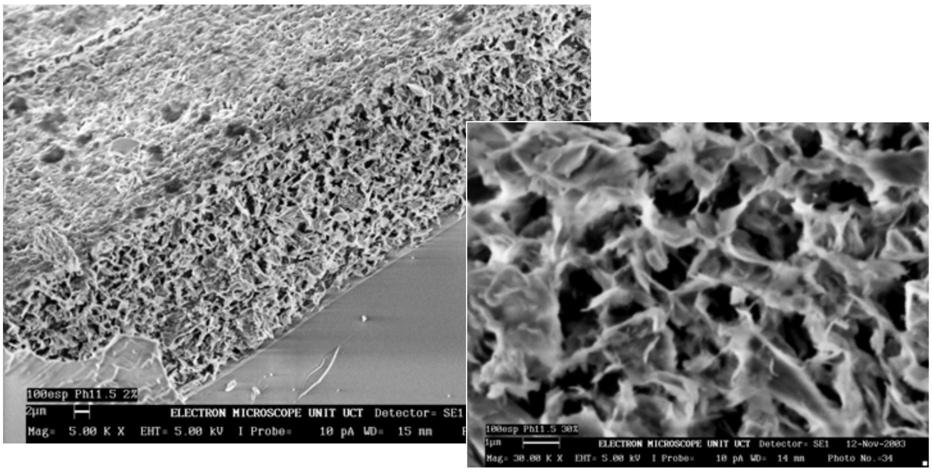

Figure 1 Electron microscope image of thickened kimberlite tailings particle orientation

Two novel polymer flocculant products have been developed by CIBA® for improving water release and the rheological properties of thickened tailings. The two product ranges are marketed as:

- Rheomax™ DR (Density and Rheology) – The product is primarily used as a replacement for conventional polyacrylamide flocculants which are dosed prior to the thickening step. The product is designed to improve sedimentation and reduces the yield strength of the thickened underflow product.
- Rheomax™ ETD (Enhanced Tailings Disposal) – The product is applied to the thickened tailings after the thickening step, prior to deposition at the disposal site. The product is designed to improve the release and recovery of water at the disposal site.

3 Methodology

A test programme designed to determine the water release properties of the Rheomax™ ETD product only on thickened kimberlitic tailings was conducted by Debswana in partnership with Paterson and Cooke, Senmin (supplier of CIBA® Rheomax™ products) and Larox (supplier of filtration equipment).

3.1 Disposal site system application tests

Senmin were tasked to conduct a Rheomax™ ETD product selection and dose evaluation on Orapa and Jwaneng mine ore types and to conduct laboratory tests to establish the amount of free water that could be released by adding Rheomax™ ETD prior to depositing tailings onto the disposal site. The test procedure conducted by Senmin was as follows:

- Rheomax™ ETD products made up to 0.25% (by mass) dosing strength.
- Kimberlitic slurries from Orapa and Jwaneng mines (-300 μm) were made up to three slurry densities 1.18 t/m^3; 1.26 t/m^3 and 1.3 t/m^3 (solids dry density of 2.7 g/cm^3).
- A known volume of slurry was sampled in a 500 ml beaker to which an appropriate dose of Rheomax™ ETD was added.
- The contents of the beaker was poured between two beakers for 10 inversion to mix the contents.
- The slurry was poured into a 7 x 7cm circular collar resting on a 300 μm sieve suspended over a dish.
- The collar was raised and the contents allowed to drain for 3 minutes after which the slump height and diameter were measured.
- The water volume collected after 3 minutes of free draining was recorded.

3.2 Filtration system application tests

Larox were tasked to conduct laboratory vacuum filtration tests on slurries from both Orapa and Jwaneng mines using a belt filter apparatus to establish the amount of free water released after adding Rheomax™ ETD prior to a filtration process.

Preliminary tests indicated that the Orapa mine ore slurries tended to agglomerate after Rheomax™ ETD dosing and would therefore not spread evenly over the filter belt, thereby compromising the vacuum filtration efficiency. To avoid this problem the slurry feed densities needed to be diluted to 1.20 t/m^3 dosing and belt filtration. The Jwaneng mine slurries did not agglomerate after dosing and tended to spread evenly over the filter belt.

3.3 Settling tests

Settling tests were performed by Debswana on the Orapa mine ores to establish if the addition of Rheomax™ ETD to thickened tailings would alter the ultimate dry density of the tailings in the impoundment. An increase in dry density would imply that the polymer had possibly re-arranged the clay particle orientation resulting in a collapse of the matrix and subsequent release of the locked pore water.

Dry density is a geotechnical term denoting the dry mass of solids per unit volume. Typical values for kimberlitic tailings impoundments are 0.9 t/m^3 (Jwaneng tailings) and 1.0 t/m^3 (Orapa No. 1 tailings dam). Metallurgists are more familiar with the term slurry density, which is the mass of solids plus water per unit volume. The dry density corresponding to a specific slurry density can be calculated using the following equation:

$$\rho_d = \frac{\rho_s\left(\rho_m - \rho_w\right)}{\left(\rho_s - \rho_w\right)} \quad , \tag{1}$$

Where:

ρ_d	=	dry density (t/m^3)
ρ_m	=	slurry density (t/m^3)
ρ_s	=	solids density (t/m^3)
ρ_w	=	water density (t/m^3).

For a slurry density of 1.35 t/m^3, the corresponding dry density is 0.576 t/m^3 (ρ_s = 2.55 t/m^3, ρ_w = 1.00 t/m^3).

Tests were conducted using one litre samples of tailings at densities of 1.25, 1.30 and 1.35 t/m^3 for both, untreated samples and those dosed with 265 g/t of Rheomax™ ETD product.

3.4 Cost comparison study baseline

The Rheomax™ ETD dosed systems were compared with the base case thickening technologies currently in operation in Debswana, namely the conventional, high density and paste systems. All cases considered the separate disposal of tailings and grits though the incorporation of a de-sanding plant.

The relevant design, costing and water consumption parameters for these cases are summarised in Table 1.

Table 1 Study baseline summary

Case	Conventional	High Density	Paste
Design tonnages		1086 t/h	
Solids density		2.54 t/m^3	
Tailings density (design)	1.25 t/m^3	1.30 t/m^3	1.35 t/m^3
Tailings rheology (design)	Yield stress: 25 Pa Viscosity: ~0.0155 Pa.s	Yield stress: 45 Pa Viscosity: ~0.0245 Pa.s	Yield stress: 100 Pa Viscosity: ~0.0325 Pa.s
Tailings transport mode	Pipeline Centrifugal pumps	Pipeline Centrifugal or PD pumps	Pipeline PD pumps
Water recovery from disposal site	17%	10%	0%
Tailings dry density	0.676 t/m^3	0.795 t/m^3	0.883 t/m^3
Costing	NPC discount rates: inflation 15%, interest 10%		
Water consumption per tonne of head feed	0.750 m^3/t	0.664 m^3/t	0.615 m^3/t

4 Results

4.1 Disposal site system application tests

The key findings of the Senmin test work were:

- Rheomax™ ETD 9010 was the optimum product for maximising water recovery.
- The optimum dosage for Orapa mine ore types is in the range of 260 to 300 g/t.
- The optimum dosage for Jwaneng mine ore types is in the range of 218 to 250 g/t.

Figure 2 shows the variation of percentage "free water" versus tailings density for all the tests conducted. Although there is a great deal of scatter, the general trend is that the amount of free water reduces with increasing tailings density. The percentage of free water is defined as the ratio of the amount of water recovered to the total amount of water in the sample at the start of the test.

Figure 3 illustrates how the amount of water retained in the tailings after treatment with Rheomax™ ETD reduces with increasing tailings density.

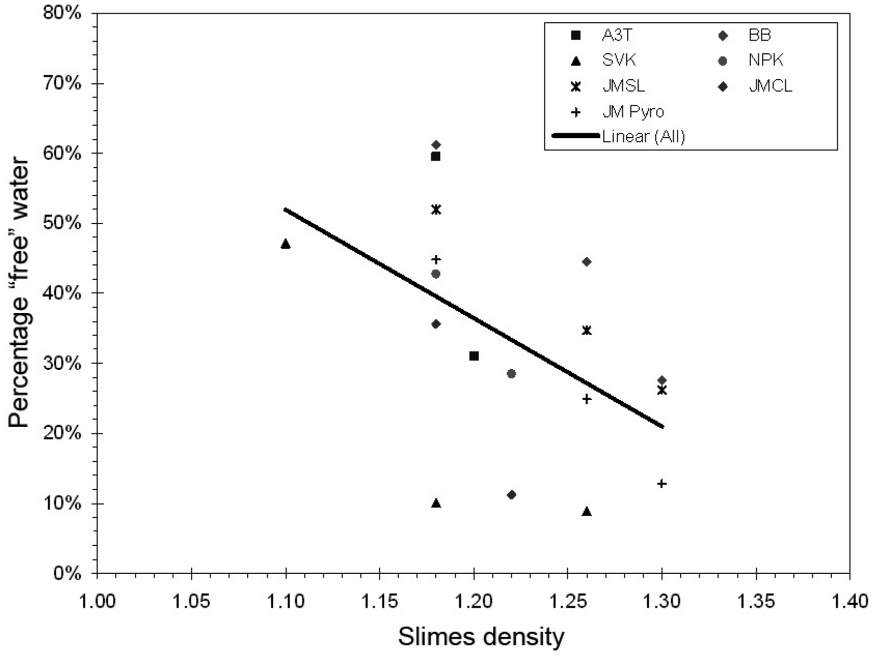

Figure 2 Percentage free water versus slimes density (t/m^3)

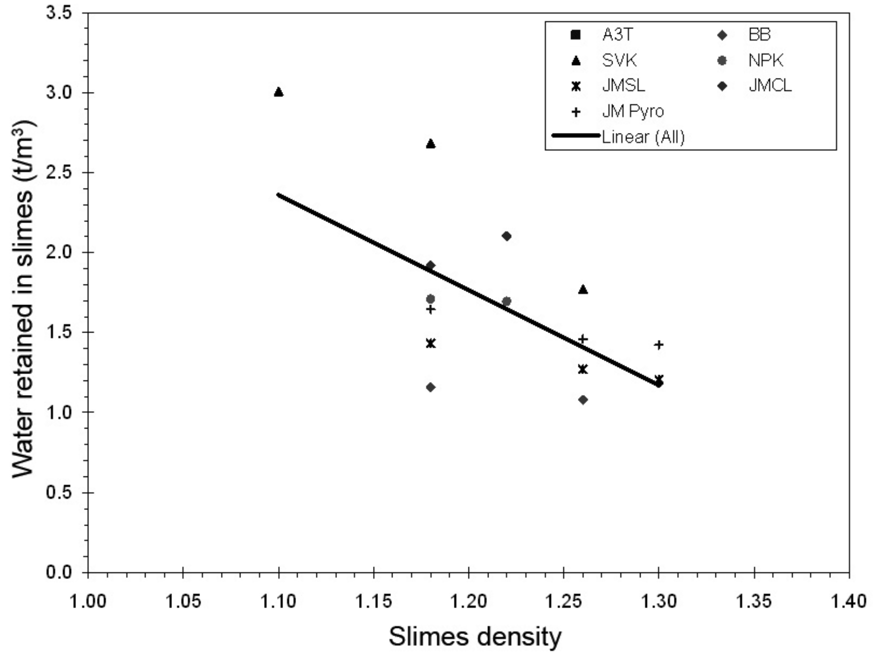

Figure 3 Water retained versus slimes density (t/m^3)

4.2 Filtration system application tests

Figure 4 describes the variation in filtration rate and cake solids content for the Orapa mine ores.

- The average filtration rate achieved is 143 kg/m^2/h for the tests with Rheomax™ ETD addition.
- The average filter cake content is 56% by mass for the tests conducted with Rheomax™ ETD addition.
- The optimal Rheomax™ ETD dosage varied between 200 and 365 g/t for the various ore types.

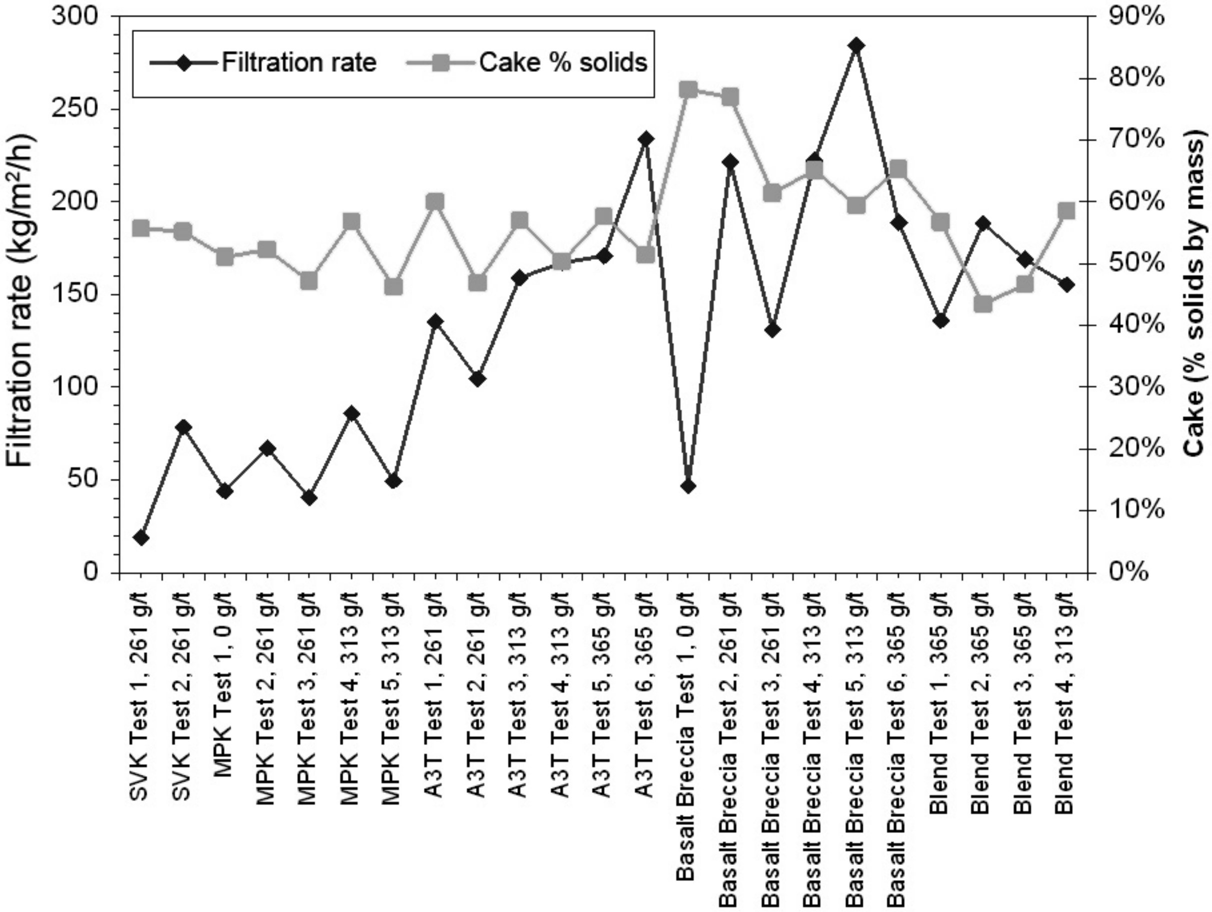

Figure 4 Orapa mine ore type filtration test results (% solids by mass)

4.3 Settling tests

The results of the settling tests show the following (Table 2):

- The dry density achieved in the measuring cylinder test is a function of the initial feed density. The data shows that to increase the ultimate dry density (and, hence reduce the impoundment water lock up), the tailings should be placed at as high a density as possible.
- Adding Rheomax™ ETD increases the achieved dry density slightly (about 0.8% on average).

Table 2 Settling test results

Initial Tailings Density	Tailings Dry Density at End of Test	
	No Rheomax™ Addition	Rheomax™ Addition
1.257 t/m^3	0.456 t/m^3	0.471 t/m^3
1.306 t/m^3	0.520 t/m^3	0.545 t/m^3
1.352 t/m^3	0.591 t/m^3	0.602 t/m^3

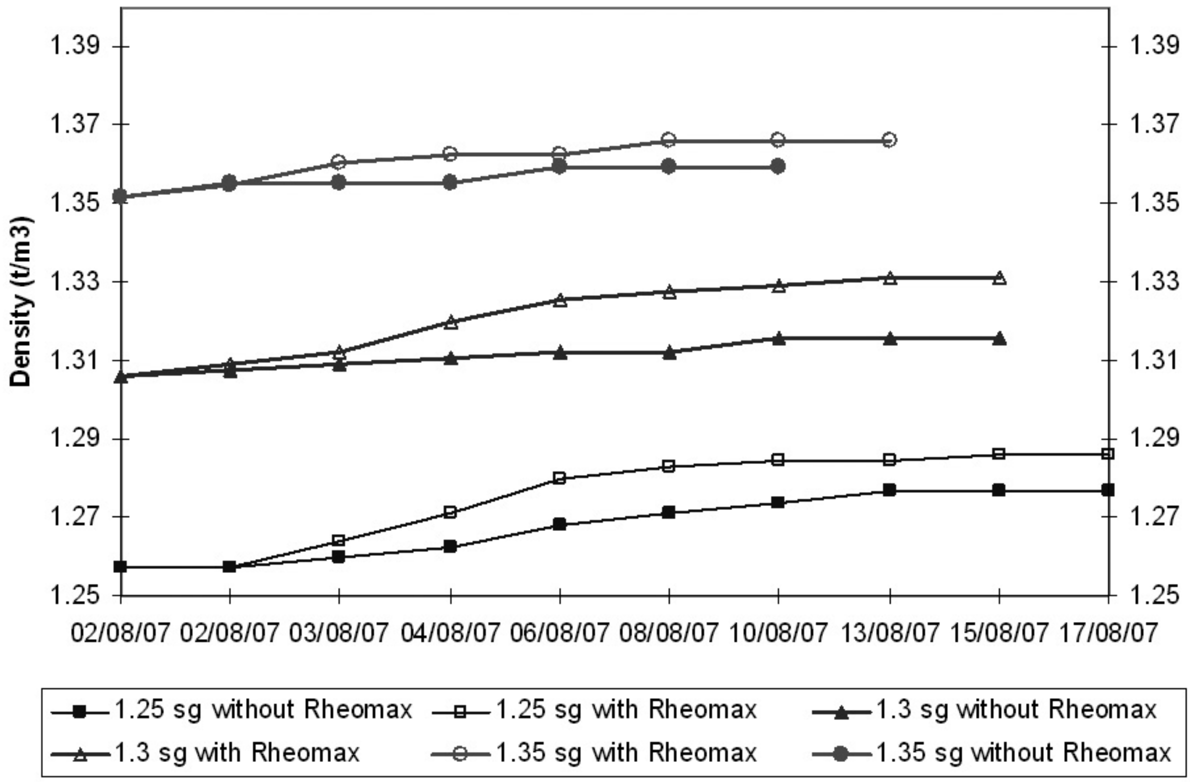

Figure 5 Settling test data

5 System cost comparison

5.1 Disposal site system application

The basis for the design and costing of the disposal site system for Orapa Mine is detailed in Table 3.

Table 3 Study baseline summary

Item	Value
Design tonnages	As per Table 1
Rheomax™ ETD dosage	260 g/t tailings
Rheomax™ ETD cost	P 30.10 / kg (Pula/ USD exchange rate (02/2008). P 6.00 for US$ 1.00)
Tailings dry density	0.8% increased compared with base case
Water recovery from disposal site	Impoundment area = 2 km^2 Evaporation rate = 2.25 m/y Rainfall = 0.37 m/y
Costing	Class 0 estimate (-20% +30%) NPC discount rates: inflation 15%, interest 10%

Figure 6 shows a basic block diagram for the proposed disposal site system. The system has the following components:

- Thickener farm comprising conventional, high density or paste thickeners.
- The pumping system will either comprise centrifugal pumps (conventional or high density options) or positive displacement pumps (high density or paste options). The tailings are transported to the disposal site via a pipeline.
- A flocculant plant located at the deposition site prepares the Rheomax™ ETD for injection into the pipeline just prior to deposition.

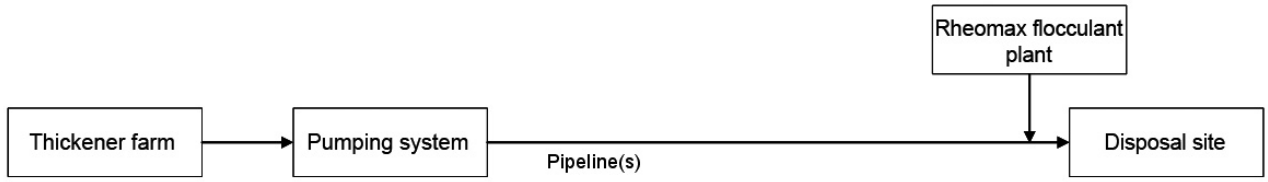

Figure 6 Block diagram — disposal site system application

The following factors have been considered in establishing the water balance:

- Due to the relatively high rise rate of 4 m/yr, most of the tailings impoundment beach will be wet.
- The dry density of the tailings in the impoundment has been estimated using the settling cylinder test results (i.e. it is assumed that the dry density with Rheomax™ ETD addition will be 0.8% higher than the base case values).

Table 4 details the expected water consumption values for the three base case systems with and without Rheomax™ ETD addition.

Table 4 Water consumption

System	Water Consumption (m^3 per tonne of head feed)	
Rheomax™ addition	No – base case	Yes
Conventional system	0.750 m³/t	0.707 m³/t (5.7% saving)
High density system	0.664 m³/t	0.628 m³/t (5.4% saving)
Paste system	0.615 m³/t	0.583 m³/t (5.2% saving)

Figure 7 shows a plot of net present cost (NPC) versus water consumption for the disposal site system and baseline systems. Although the disposal site system has the potential to reduce water consumption by about 5.5%, the life-cycle cost of the system is between 30 and 35% higher than the baseline systems.

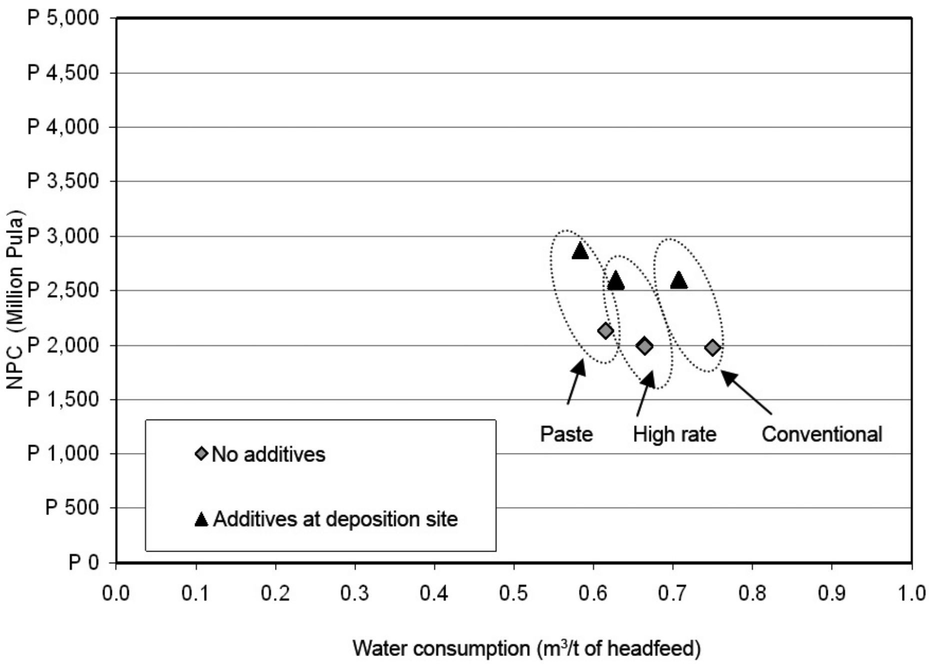

Figure 7 High level trade-off — disposal site system

5.2 Filtration system application

The basis for the design and costing of the filtration system for Orapa mine is detailed in Table 5.

Table 5 Filtration system design and costing basis

Item	Value
Design tonnages	As per Table 1
Rheomax™ ETD dosage	260 g/t tailings
Filtration rate	150 kg/m^2/h
Filter cake mass concentration	56%
Vacuum filter and vacuum pump costing	Vendor quotation
Rheomax™ ETD cost	P 30.10 / kg
Filter plant standby capacity	25%
Conveyor transport system standby capacity	Dedicated systems for #2 and #3 Plants – no standby allowance
Disposal site	Impoundment dam on top of and to the north of the #1 Plant tailings dams
Water recovery from disposal site	Zero
Costing	Class 0 estimate (-20% +30%) NPC discount rates: inflation 15%, interest 10%

Figure 8 shows a basic block diagram for the filtration system for Orapa mine. The components are:

- Conventional thickener farm.
- A flocculant plant for adding Rheomax™ ETD prior to filtration.
- Filtration plant comprising vacuum belt filters.
- Conveyor transportation system to the disposal site.

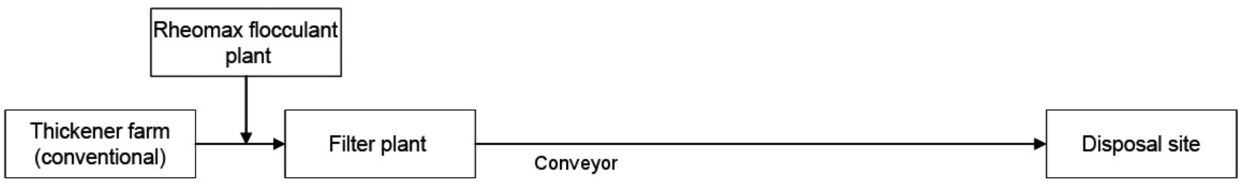

Figure 8 Block diagram — filtration system

For sizing purposes the design filtration rate is taken as 150 kg/m^2/h. As shown in, there is significant variation in the actual filtration rate achieved during the test work. The average value for the blended Orapa mine ores is 162 kg/m^2/h.

The largest Larox belt filter has a filtration area of 170 m^2. Thus the capacity of the filter for typical Orapa mine ore is 25.5 t/h. A 25% standby capacity allowance is provided for the filtration plant.

For the Orapa Number 2 Plant 21 operating filter units are required resulting in an installed requirement of 27 belt filters. The corresponding requirements for the Orapa Number 3 Plant are 23 and 29 filters respectively. Each belt filter would require a 630 kW vacuum pump.

Table 6 compares the water consumption per tonne of plant head feed for the filtration system with the baseline systems. The filtration system results in significantly lower water consumption compared with the baseline systems. Since the current Orapa Number 2 Plant has a water consumption of 0.855 m^3/t, the filtration system will result in a 53% water saving.

Table 6 Water consumption

System	Water Consumption (m^3 per tonne of head feed)
Filtration system	0.398 m^3/t (combined)
Conventional system	0.750 m^3/t
High density system	0.664 m^3/t
Paste system	0.615 m^3/t

Figure 9 shows a plot of net present cost (NPC) versus water consumption for the filtration and baseline systems.

Although the filtration system has the potential to significantly reduce water consumption, the life-cycle cost of the system is approximately double that of the baseline systems.

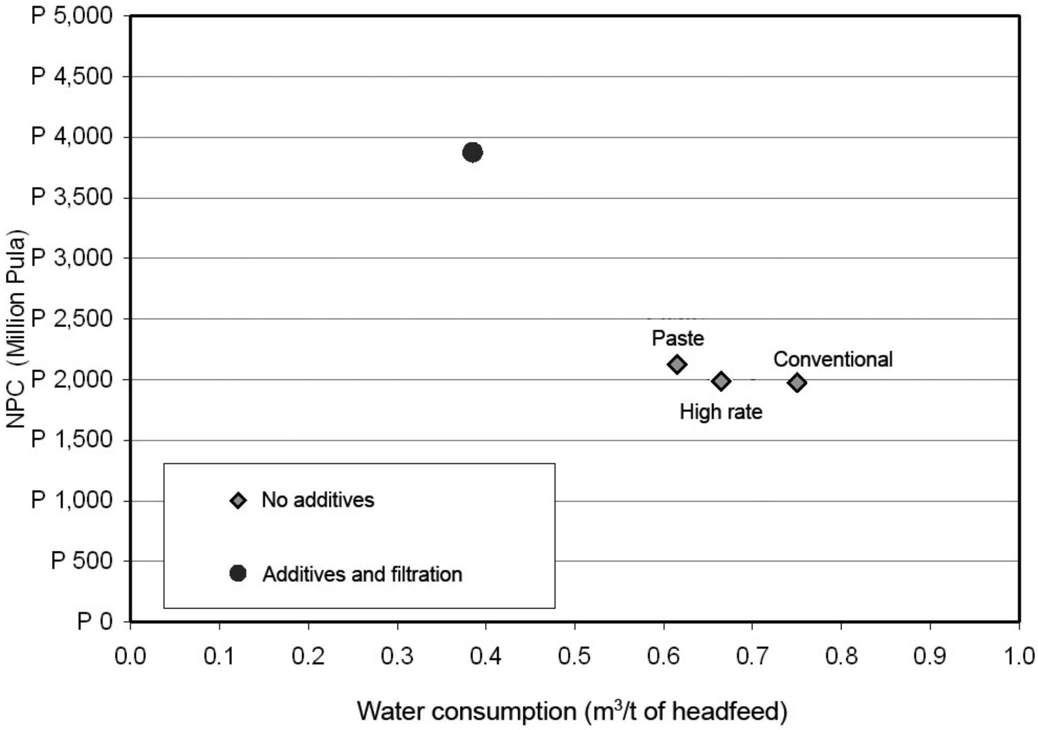

Figure 9 High level trade-off — filtration option

6 Conclusion

The current study specifically for Orapa mine has highlighted that the largest percentage of water lost to the process is pore water locked up in the tailings impoundment. Site observations and settling test data indicate that even for paste tailings there is potential for water release as the tailings consolidates.

Small scale settling cylinder tests indicate that the disposal site system application could result in a 5% reduction in water consumption although this will significantly increase the NPC cost by between 30 and 35%. The main cost contributor is the high cost of the Rheomax™ ETD and therefore based on the test data available, adding Rheomax™ ETD at the deposition site is not a cost effective option for Orapa Mine.

The proposed filtration system application for Orapa Number 2 Plant will comprise three conventional thickeners, 27 installed belt filters and vacuum pumps and a dedicated conveyor transport system to the disposal site. The Orapa Number 3 Plant system will have 29 installed belt filters. The filtration system has a potential water consumption of 0.40 m^3 per tonne of head feed which compares favourably with the paste-only system which has a water consumption of 0.62 m^3/t.

The capital cost of the filtration system however, is high owing to the large number of installed belt filters. The NPC cost of the filtration system is 4.3 billion Botswana Pula. This is more than double the NPC of the paste-only system 2.1 billion Botswana Pula. In addition there is significant technical risk associated with the filtration system:

- The Orapa tailings have a very low filtration rate requiring the installation of a large number of belt filters. In addition, there is a wide range of filtration rates for the various ore types. This may result in situations where the filtration plant is unable to cope with the material being treated, leading to a plant bottle neck.
- The conveyor transport of the filter cake has not been investigated. This is an area of significant risk especially at transfer points and upward sloping sections.

Owing to the high cost and significant technical risk, it is recommended that the filtration system application is not pursued further for Debswana operations.

Acknowledgements

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