TAILINGS DISPOSAL: AN APPROACH TO OPTIMIZE WATER AND ENERGY EFFICIENCY

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Abstract

An approach to the design of a tailings disposal system is presented using an example from a platinum project on the eastern limb of the Bushveld Complex as a base case. The design is driven by two inputs: namely, maximizing water recovery and minimizing power cost, expressed as cubic metres and kilowatts per ton of solids deposited on the tailings storage facility respectively. The approach considers low-, medium-, and high-density platinum tailings and uses material-specific aspects such as thickening and rheology to determine the most economical option. An analysis based on direct capital and operating cost (water and electricity) shows that the medium-density scenario results in the lowest total cost per ton of tailings deposited, even though this system results in the highest electricity consumption per ton of tailings deposited. As the cost of water and electricity is likely to increase in the future, the higher-density tailings disposal options become more economical, with the paste option the preferred option.

Introduction

The reasons for considering paste and thickened tailings, as opposed to conventional tailings, originate from many economical, engineering, environmental, and social benefits. In a recent paper, Fourie (2012) described the benefits associated with paste and thickened tailings disposal as '*largely achieving its benefits*' for capital cost savings and '*achieving its benefits*' for water savings.

A study on high-density platinum tailings systems (Paterson, 2004) showed that significant water savings can be achieved at nominal additional energy cost, by increasing the tailings density to 1.7 t/m^3. Other studies (Rayo *et al.*, 2009) have shown that water and energy savings for high-density tailings are not always that evident, with no distinct economic differences between low-, medium-, and high-density tailings disposal.

Water and energy costs will vary according to individual mine tailings, mineralogy, size grading, and rheology. It is with this uncertainty in mind that a trade-off in water and energy consumption of a platinum mine on the eastern limb of the Bushveld Complex was performed to determine the optimum thickening and tailings disposal scenario.

Low-, medium-, and high-density tailings disposal

The following terms define the platinum tailings concentration range used in this study:

i) Low-density tailings (conventional) i.e. 50-59 per cent solids

ii) Medium-density tailings (thickened) i.e. 60-70 per cent solids

iii) High-density tailings (paste) i.e. >70 per cent solids.

The key process specifications and assumptions used in the trade-off study are presented in Table I.

Table I-Tailings process specifications

Parameter	Value
Design tonnage	183 t/h
Solids density	3600 kg/m^3
Particle size P_{75}	75 µm
Power cost	0.30 rands per kWh
Raw water cost	4.00 rands per kℓ

The properties of the thickened tailings under these concentration ranges are shown in Figure 1 and Table II.

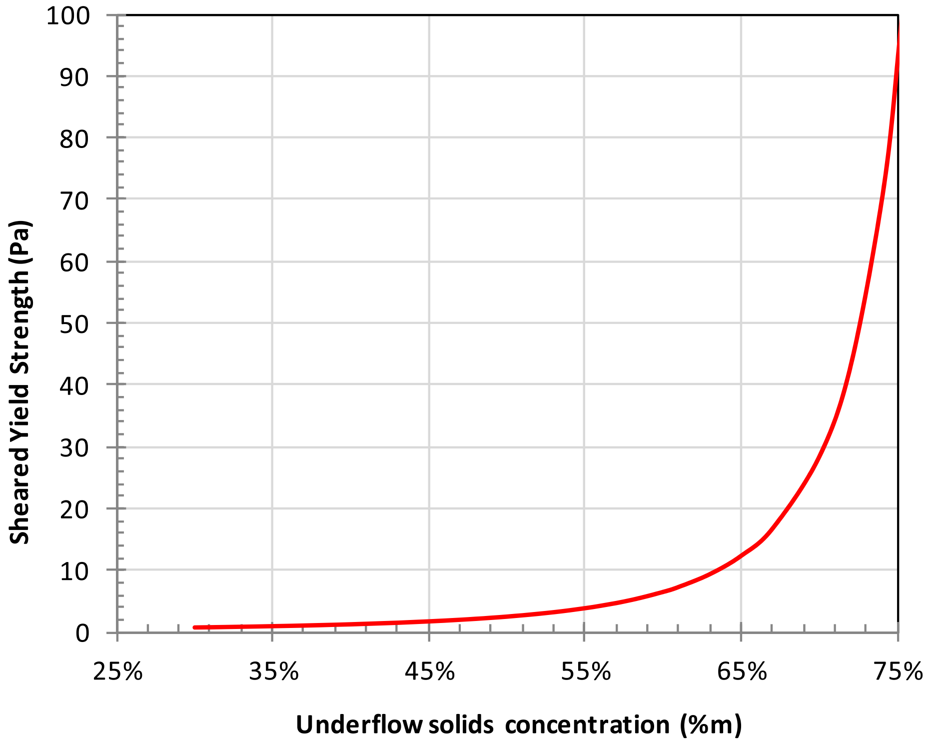

Figure 1-Tailings rheological properties

Table II-Tailings properties

	Low-density tailings	Medium-density tailings	High-density tailings
Concentration (%m)	50	60	75
Slurry density (t/m^3)	1.565	1.765	2.182
Solids transported (t/h)	183	183	183
Water transported (m^3/h)	186	124	62
Sheared yield stress (Pa)	2.4	6.4	92
Max water return (%)	43	31	12

Low-, medium-, and high-density tailings disposal rely on different process equipment. The selection of thickening, pumping, and piping equipment will depend on the degree of thickener underflow density targeted.

For example, high-rate thickeners would be selected to generate low- to medium-density underflow tailings, with low-pressure slurry pumps and piping required for tailings transfer; high-compression thickeners would be selected for medium- to high-density tailings due to the presence of picket rakes, which allow for better dewatering. Higher-pressure slurry pumps and piping would be required to handle higher pressure requirements. Paste thickeners would be selected in order to maximize underflow density, since both picket rakes and high sidewall height contribute to enhanced consolidation, while positive-displacement pumps and high-pressure piping, valves, and instrumentation is required for tailings transfer.

In order to size the various types of thickeners, a solids throughput of 0.8 $t/m^2.h$ was selected, which is typical for platinum flotation tailings. Based on this parameter, one 17 m diameter thickener unit is required in all cases; however, the type of thickener selected varies according to the underflow density targeted.

Pumps and piping are selected to maintain minimum flow rates in the pipeline to prevent blockages.

Low-density tailings disposal

The low-density tailings disposal system is shown in Figure 2. The thickening requirements include a single 17 m diameter high-rate thickener and a flocculant make-up and dosing plant capable of dosing at a rate of 50 g/t.

Tailings are transported to the tailings storage facility (TSF) at a flow rate of 233 m^3/h and deposited by means of spigots from a ridge and by cyclones on the opposite side. At this flow rate the conventional tailings disposal system requires five centrifugal slurry pumps with 90 kW motors each (a total of 450 kW installed power) at a pump discharge pressure of approximately 2500 kPa. Steel piping is required for the initial part of the pipeline, which is followed by lower pressure-rated HDPE piping as the pressure along the pipeline decreases.

Return water is pumped back to the plant at a nominal flow rate of 80 m^3/h, which requires a single centrifugal pump with a 30 kW motor and a HDPE pipeline.

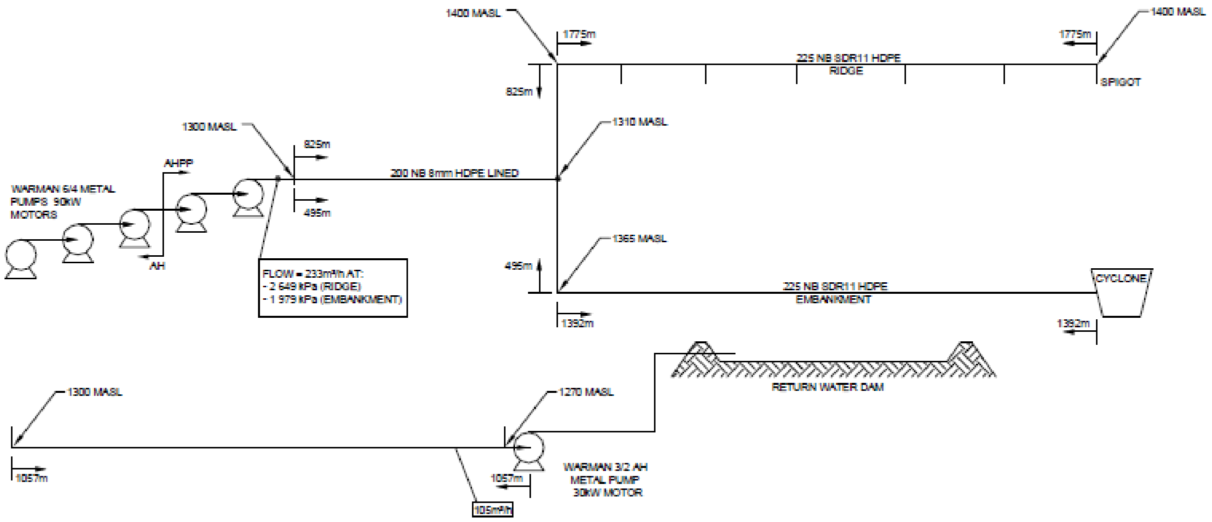

Figure 2-Low-density tailings disposal and water recovery

Medium-density tailings disposal

The medium-density tailings disposal system is shown in Figure 3. The thickening requirements include a single 17 m diameter high-compression thickener and a flocculant make-up and dosing plant capable of dosing at a rate of 50 g/t.

Medium-density tailings is transported to the TSF at a flow rate of 172 m^3/h and is deposited by means of spigots from a ridge and cyclones on the opposite side. At the increased density the medium-density tailings disposal system requires an additional high-pressure centrifugal slurry pump, resulting in six centrifugal pumps with 90 kW motors each (a total of 540 kW installed power). This system requires an increased discharge pressure of approximately 3 700 kPa. This is considered to be close to the maximum operating pressure for centrifugal slurry pumps. Steel and HDPE piping is required as for the medium-density tailings disposal case.

Return water is pumped back to the plant at a flow rate of 38 m^3/h, which requires a single centrifugal pump with an 18.5 kW motor and a HDPE pipeline.

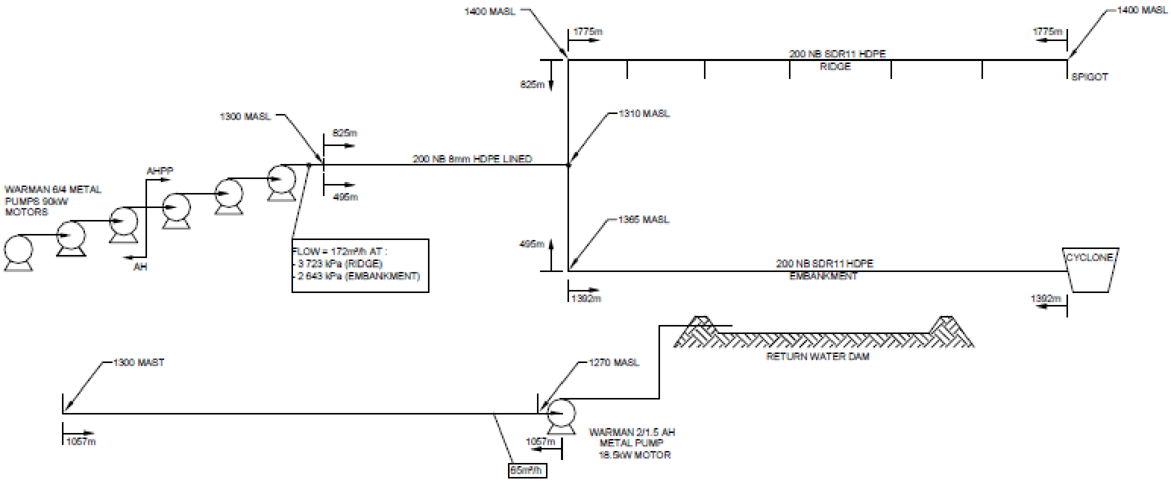

Figure 3-Medium-density tailings disposal and water recovery

High-density tailings disposal

The high-density tailings disposal system is shown in Figure 4. The thickening requirements include a single 17 m diameter paste thickener and a flocculant make-up and dosing plant capable of dosing at a rate of 50 g/t.

Thickened tailings is transported to the TSF at a flow rate of 111 m^3/h and is deposited by means of spigots from the embankment side only. At the increased density the tailings disposal system requires a positive-displacement pump with a maximum discharge pressure of 5 800 kPa with a 315 kW motor. The positive-displacement pump operates at higher efficiencies compared to the centrifugal pumps of the low- and medium-density tailings. Only steel piping with a high-pipeline pressure rating is required, as for the paste tailings disposal case.

Return water is pumped back to the plant and requires a single centrifugal pump with a 18.5 kW motor. This is considered to be rain water only, as the paste results in no significant bleed water.

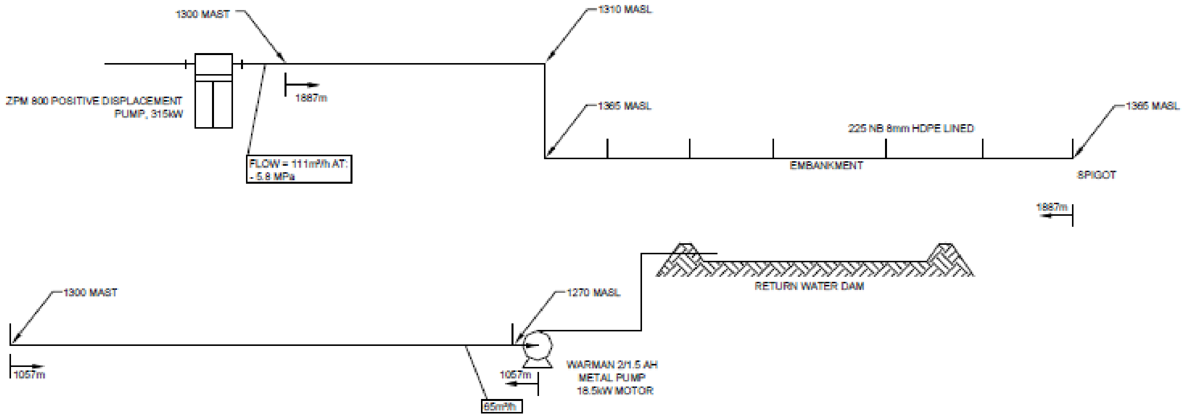

Figure 4-High-density tailings disposal and rain water recovery

Direct capital costs

The equipment that significantly affects the direct capital cost is shown in

Table III for the low-, medium-, and high-density tailings disposal systems.

Thickener capital costs increase with increasing underflow density requirement. For equivalent sized thickener units, and normalizing on the high-rate thickener cost, the high-compression thickener and the paste thickener costs are 1.22 and 1.57 times more respectively. The capital cost for the flocculant make-up and dosing plants are the same in all cases.

Pumping and piping capital costs also increase with increasing thickener underflow densities. The increase in capital cost is not as significant from low- to medium-density tailings as it is from medium- to high-density tailings.

Table IV shows that low- and medium-density tailings disposal have very similar capital costs. Both of these systems have very similar pumping and piping requirements, and therefore the close comparison is not surprising. The direct capital cost of the high-density tailings disposal scenario is significantly higher than the low- and medium-density tailings scenarios. Above 4 000 kPa pump discharge pressure, the capital costs associated with pumps, piping, and instrumentation increase significantly. High-density pumping is achieved by a high-pressure positive-displacement pump with significant cost implications. The high-density tailings disposal system also requires high-pressure piping, valves, and instrumentation.

The high-density tailings disposal system results in significantly higher direct capital costs, approximately double the costs of conventional and thickened tailings.

Table III-Major equipment requirements

System	Requirements		
	Thickening	Pumping (duty only)	Piping
Low-density tailings	1 x 17 m high-rate thickener Flocculant plant	3 × Warman 6/4 AH metal pumps or similar, each with a 90 kW motor 2 × Warman 6/4 AHPP metal pumps or similar, each with a 90 kW motor 1 × Warman 3/2 AH metal pump or similar, with a 30 kW motor	200NB steel pipe, 4.5 mm wall thickness, 8 mm HDPE-lined, 4 000 kPa flanges (825 m) 225NB HDPE pipe, SDR11, 1 000 kPa flanges (3167 m) 180NB HDPE pipe, SDR17, 1 000 kPa flanges (1057 m)
Medium-density tailings	1 x 17 m high-compression thickener Flocculant plant	3 × Warman 6/4 AH metal pumps or similar, each with a 90 kW motor 3 × Warman 6/4 AHPP metal pumps or similar, each with a 90 kW motor 1 × Warman 2/1.5 AHPP metal pump or similar, with a 18.5 kW motor	200NB steel pipe, 4.5 mm wall thickness, 8 mm HDPE lined, 4 000 kPa flanges (825 m) 200NB HDPE pipe, SDR11, 1 000 kPa flanges (3167 m) 160NB HDPE pipe, SDR17, 1 000 kPa flanges (1057 m)

Table IV- Total direct capital costs

	Low-density tailings	Medium-density tailings	High-density tailings
TOTAL DIRECT COST	R 9 351 000	R21 051 000	R39 012 000
Preliminary and General (15%)	R2 903 000	R 3 158 000	R 5 852 000
Engineering and Admin (8%)	R1 548 000	R1 684 000	R3 121 000
Contingencies (10%)	R2 380 000	R2 589 000	R4 798 000
GRAND TOTAL	R26 182 000	R28 482 000	R52 783 000

Operating costs

Water consumption

The overall plant water consumption for each thickening scenario is presented in Figure 5 and

Table *V*. The water consumption calculations take into consideration losses at the TSF due to interstitial losses only – i.e. evaporative losses taking place at the TSF and the return water dam as well as seepage losses are not included. The data indicates that there is a general decrease in water consumption as the thickener underflow density increases. Worst-case water consumption occurs during the winter season due to the absence of additional precipitation.

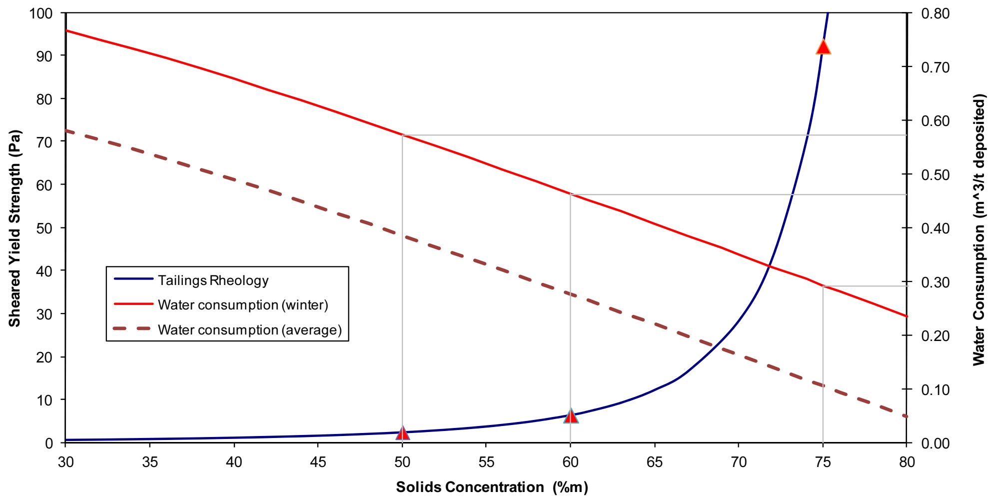

Figure 5-Water recovery

Table V-Water consumption

	Water consumption	
	Winter	Annual average
Low-density tailings	0.57 m^3/t solids	0.39 m^3/t solids
Medium-density tailings	0.46 m^3/t solids	0.28 m^3/t solids
High-density tailings	0.29 m^3/t solids	0.11 m^3/t solids

Power consumption

The power consumption per ton solids deposited for each thickening scenario is given in Table VI. The power consumption for the low-density tailings is the most energy-efficient, while the medium-density tailings disposal option is the least energy-efficient. It is evident that both slurry density and flow rate play a role in determining the most energy-efficient option as there is no linear increase in absorbed power as the slurry density increases.

Table VI-Power consumption

	Absorbed power	Power consumption
Low-density tailings	400 kW	2.2 kWh /t solids
Medium-density tailings	463 kW	2.5 kWh /t solids
High-density tailings	415 kW	2.3 kWh /t solids

Total operating costs

The total operating costs are based on the following costs:

i) Water cost: R4.00 per kl
ii) Power cost: R0.30 per kWh
iii) Flocculant cost: R32.00 per kg
iv) Maintenance: 5 to 10 per cent of capital costs

The annul water and electricity costs are shown in Table VII and Table VIII. The annual water costs decrease with increasing tailings density as a result of water savings. The annual electricity cost of the medium-density tailings disposal option is the highest.

Table VII-Annual water cost

	Total cost		
Water cost	Low-density tailings	Medium-density tailings	High-density tailings
R4.00/kℓ	*R2 871 000*	*R2 224 000*	*R1 951 000*

Table VIII-Annual electricity cost

	Total cost		
Electricity cost	Low-density tailings	Medium-density tailings	High-density tailings
R0.3/kWh	*R946 000*	*R1 094 000*	*R982 000*

The total annual operating costs, which include water and electricity as well as maintenance and flocculant costs for each tailings disposal option, are shown in Table IX. There is no real significant difference in the operating costs, although there is a slight decrease in annual operating costs as the tailings density increases.

Table IX-Total annual operating costs (water and electricity, maintenance, flocculant)

	Low-density tailings	Medium-density tailings	High-density tailings
Total annual operating costs (Water at R 4.00/kl) (Electricity R0.3/kWh	*R6 276 000*	*R5 833 000*	*R5 532 000*

Total combined costs

Table X shows the total combined costs (capital and operating costs) over a 25 year life of mine. The medium-density tailings system is the optimum thickening scenario for this case, although the overall costs for all the systems are very similar, and the final choice of system will depend largely on whether the mine is capital- or operating-cost sensitive.

Table X-Total combined costs (25 years)

Tailings option	Total cost
Low density	R183 073 000
Medium density	R174 304 000
High density	R191 082 000

Table XI shows the total combined costs at increasing water and electricity costs. With an increase in water cost to R13.00 per kilolitre (case 2), medium-density tailings disposal is only slightly more economical than high-density tailings disposal. With an additional increase in electricity cost to R0.60 per kilowatt-hour (case 3), high-density tailings disposal becomes the most economical. The analysis shows that as the water costs increase the higher-density options become more economical over the life–of-mine period.

Table XI-Total combined costs (25 years) –water and electricity sensitivity

Tailings option	Case 1 (R4.0/k ℓ, R0.3/kWh)	Case 2 (R13.0/kℓ, R0.3/kWh)	Case 3 (R13.0/kℓ, R0.6/kWh)
Low density	*R183 073 000*	*R344 545 000*	*R368 193 000*
Medium density	*R174 304 000*	*R299 398 000*	*R326 756 000*
High density	*R191 082 000*	*R300 842 000*	*R325 394 000*

Conclusions

For this specific platinum mine the medium-density tailings disposal system appears to be the most economical option over the life–of-mine period. The study shows that as the cost of water and electricity is likely to increase in the future, the higher-density tailings disposal options become more economical, with the paste option the preferred option at high water and electricity costs.

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