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Review of alternative dewatering technologies for application to South African platinum tailings

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Abstract

The consideration of alternative tailings management technologies is becoming increasingly important in the mining industry. A combination of factors drives this, including changes in legislation and standards, as well as increased focus on the safety of surrounding communities.

The Global Industry Standard on Tailings Management (GISTM) has been developed as part of the industry commitment to strive for reduced overall risks, potential threats, hazards and impacts (including harm to people and the environment) (International Council on Mining & Metals [ICMM] 2020). Several mining companies have committed to voluntary conformance to the GISTM worldwide and are already working to align current and future operations with the standard. The GISTM is particularly relevant to South African operators because local legislation is expected to be revised to align with the GISTM as minimum standards of international good practice are adopted.

Dewatering technologies are being developed at a fast pace, and the improved performance and throughput of equipment has the potential to make new types of tailings disposal systems feasible. A discussion of the performance of alternative tailings dewatering technology options for South African platinum tailings and the potential impact on the multi-criteria analysis used to select new systems is presented. Various thickening and filtration technology options are considered, along with the implications for transportation, placement and platinum tailings storage facilities design.

Keywords: *alternative tailings, multi-criteria analysis, thickening, filtration, surface disposal, platinum*

1 Introduction

1.1 Platinum mining in South Africa

World platinum group metals (PGM) reserves total approximately 3,200 Moz and are found in very limited geographic locations. South Africa accounts for 88% of PGM reserves, with Zimbabwe, Russia, North America and the rest of world accounting for the remaining 12% (Mudd 2010). South Africa currently produces over 60% of newly mined PGMs and over 80% of platinum.

In South Africa, PGMs are recovered from poly-metallic sulphide ores that contain PGM-bearing minerals. These ores have PGM concentrations in the order of 2 to 5 g/t in the run of mine (ROM) ore (Glaister & Mudd 2010). The recovered PGMs are a combination of platinum, rhodium and palladium, but the ore also yields significant quantities of base metals (Zientek et al. 2014). Typically, only 3% of the milled ore reports to concentrate for smelting and the remaining 97% reports to tailings. South African annual PGM output (120 million metric tonnes in 2023) at an ore grade of 2 to 5 g/t translates to 24 to 60 million tonnes of tailings generated per annum by 24 active mining operations (as at 2022), excluding any entrained waste rock that reports to tailings.

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It is important to note that PGM mining accounted for 22 to 35% of South African mining industry revenue from 2022 to 2024 (Price Waterhouse Coopers 2023, 2024) and 35% of employment in the South African mining industry in 2022 (Statistics South Africa [Stats SA] 2022). In a country with an official youth unemployment rate of over 45.5% (Stats SA 2024), it is important that the mining industry finds workable solutions for tailings in which the miners and local South Africans can benefit from the mineral resources, but which also create a sustainable legacy going forwards.

1.2 Tailings management and tailings storage facility design current practice

Current platinum tailings storage facilities (TSFs) are typically designed for upstream construction and use a spigot distribution system or on-wall cyclone deposition systems (Knight et al. 2012). Both spigot and cyclone deposition systems require starter walls built from imported material. On TSFs with spigot deposition the wall is then gradually raised using dried out, compacted tailings (Grant-Stewart 2020). In cyclone deposition systems, the particle sizes are separated using centrifugal forces in the cyclone and the TSF wall is raised using the coarse, low moisture content cyclone underflow (Vick 1990). The fine, high moisture content cyclone overflow is directed to the centre of the TSF, after which most of the water either evaporates or is decanted from the TSF. A major benefit of cyclone designs is the increased permeability of the wall, which improves the drainage and can allow increased TSF design rise rates (Grant-Stewart 2020). Although upstream TSFs can be responsibly and sustainably operated in the South African climate, this construction method is not widely accepted in other jurisdictions. Internationally based companies operating in South Africa are increasingly required to adhere to regulations over and above South African legislation, contributing to alternative TSF designs being considered for new TSFs planned in South Africa (Grant-Stewart 2020). Platinum tailings has also been classified as a ‘potentially hazardous waste’ under South African environmental legislation, necessitating the lining of new TSFs and leading to a substantial increase in upfront cost for the TSF construction (Spies 2020).

1.3 Global Industry Standard on Tailings Management and implications for future tailings management in South Africa

The publication of, and commitment to, the Global Industry Standard on Tailings Management (GISTM) is particularly relevant to South African operators because local legislation is expected to be revised to align with the GISTM as minimum standards of international good practice are adopted. Conformance with GISTM Requirement 3.2 requires the TSF design team to consider a range of tailings management options available, including tailings dewatering alternatives. These options are then assessed using a multi-criteria alternatives analysis before choosing a final, preferred tailings management system and TSF design. Trading-off these options is a multidisciplinary activity that requires broad stakeholder engagement supported by the technical expertise of the tailings management system design team.

Advances in thickener, flocculant (Kujawa et al. 2019), filter (Amoah 2024; Hahn 2024) and even mineral flotation technology (Taguta et al. 2023; Anglo American 2023) have the potential to create new opportunities for alternative tailings management systems that could include paste tailings, filtered stacked tailings or combinations of these options.

1.4 Holistic selection of tailings storage facilities systems

High-level trade-off assessments of alternative tailings options are required at the beginning of any GISTM-compliant greenfields project. In order to approach these with a holistic view, a multidisciplinary team needs to be engaged to identify potential TSF systems and then, once these have been shortlisted, assess the environmental, socio-economic and technical aspects as well as project economics.

The first step of this process is for the TSF design team and the dewatering technology team to identify holistic storage systems that are achievable, both in terms of dewatering technology performance and TSF design (Crystal & Jansen 2024). To identify potential dewatering technology systems and develop the process flow sheets during the early stages of design, the dewatering technology team needs to have a thorough understanding of the tailings, a reliable database of testwork for equipment sizing and selection, and a good understanding of the equipment and power costing. Vitally, the dewatering technology team needs to liaise closely with the TSF design team to ensure that the selected options can satisfy the geotechnical requirements of the system (Grohs et al. 2024).

Once the holistic tailings dewatering and storage system options have been identified they need to be traded-off using a multi-criteria analysis system. A number of tools are available to assist the design team in selecting the most appropriate TSF technology. One tool that has commonly been adopted in industry is the Multiple Accounts Analysis (MAA), as described in *A Guide to the Management of Tailings* version 3.2, published by the Mining Association of Canada (MAC) in 2021.

1.5 Platinum dewatering

This paper provides an overview of platinum tailings characteristics observed during testwork and design; available dewatering technologies; and a discussion of the performance of platinum tailings observed in laboratory tests and full-scale operation. The relationship between the dewatering technology selection, dewatered tailings transportation and TSF design is also discussed, with an aim to outlining important considerations when selecting complete tailings management systems for further detailing in the design.

2 Platinum tailings

The first step to understanding platinum tailings produced in South Africa is to understand the basics of the orebody, mining and processing required. As such, an overview of the South African orebodies, mining and processing is presented, followed by a summary of the historic platinum tailings properties observed during laboratory testing.

2.1 Orebody

Platinum mining operations in South Africa are located on the Bushveld Complex, in three regions commonly referred to as the Western, Eastern and Northern Limbs.

The Bushveld Complex includes three distinct mineral-bearing reefs (Cawthorn 2010):

- Merensky Reef – a narrow (typically 1 to 2 m) reef, containing relatively high PGM grades and high ratios of platinum (versus palladium). It occurs in the Bushveld Complex Western and Eastern Limbs
- UG2 Reef – also a narrow (typically 1 m) chromite-rich reef which lacks the high yield of gold, copper and nickel byproducts of the Merensky Reef. It occurs in the Bushveld Complex Western and Eastern Limbs
- Platreef – a much wider reef (typically 50 to 150 m) with lower PGM values but a higher base metal content. It occurs in the Northern Limb of the Bushveld Complex.

The grain size of PGM-bearing minerals is small, 5 to 20 µm in UG2 ore and up to 150 µm in Merensky ore (Hay & Roy 2010). As a result, extensive grinding is required to liberate the PGM-bearing minerals from the host rock. The exact grinding target varies depending on the mine, processing plant and mineral economics.

2.2 Mining and processing

The mining of PGM-bearing ores is through a combination of underground and open pit operations. The ROM material is fed to the concentrator plant where it is crushed and milled, and the valuable minerals are concentrated using flotation. This concentrate is then smelted to produce a PGM-rich Ni-Cu matte from which the PGMs are extracted at a precious metals refinery. Ni-Cu byproducts are extracted at a separate base metals refinery.

The final grinding target particle size distribution (PSD) for a UG2 circuit is typically 70 to 80% passing 75 µm (Hay & Roy 2010; Valenta & Mapheto 2010; Lameck et al. 2019). Ultrafine grinding to 80% passing 53 µm can be used to improve recovery (Valenta & Mapheto 2010), but the additional comminution cost needs to be offset by a larger gain in revenue. The larger grain size of Merensky ore means that a slightly coarser grind of 55 to 65% passing 75 µm can typically achieve the required liberation and recovery for the process (Hay & Roy 2010).

Coarse particle flotation technology is also being investigated for future operations because it has the potential to reduce grinding costs and improving flotation circuit performance by targeting the separation of larger, high-PGM-grade particles from gangue before further milling is performed (Taguta et al. 2023). This will also have an impact on future tailings streams as it will reduce the amount of fines and may facilitate alternative tailings disposal methods.

2.3 Platinum tailings characteristics

Tailings properties are largely a function of (1) the mineralogy of the feed ore, (2) the grind size required for optimal recovery and operation of the flotation recovery circuit, and (3) the minerals targeted for recovery. Depending on the feed ore and concentrator plant process, the tailings properties and behaviour can vary significantly.

2.3.1 Solids density

The tailings solids density is influenced by the feed ore mineralogy and whether chromite recovery is included in the concentration plant circuit. Merensky Reef ore density is typically 3.0 to 3.2 t/m^3, while UG2 chromitite ore can have densities of 3.8 to 4.2 t/m^3. Inefficiencies in mining and the resultant entrainment of waste rock widens the mined material solids density range from the Merensky Reef to between 2.7 and 3.5 t/m^3 and between 3.4 and 4.6 t/m^3 from the UG2 Reef (Zientek et al. 2014). Platinum tailings solids densities observed range from 2.9 to 3.7 t/m^3. However, chromite removal can have a significant impact on the tailings density and has been observed to reduce the density of tailings from the same ROM material from 3.6 t/m^3 to 3.4 t/m^3. The bulk density of the tailings stream is a function of both the solids density and the grind size.

2.3.2 Particle size distribution

Historic tailings PSD envelopes from tailings samples are compared with typical grind targets in Figure 1. The data illustrate that the actual tailings PSD can vary significantly from the typical operating target. The variation can be caused by changing mine grinding targets, performance or operating conditions. Sub-optimal operation, upset conditions in the processing plant, variation in the ore mineralogy or any number of factors can influence the tailings properties. Paterson (2004) reports the PSD variations observed on a single mine tailings system. Figure 2 shows a scanning electron microscope image of a platinum tailings sample. The particle shape is relatively angular, with a large range of particle sizes.

Two conclusions can be drawn from the above: (1) the tailings stream for each mine should be characterised and understood, and (2) the tailings system needs to be robust and able to handle sub-optimal operation when there are upset conditions upstream.

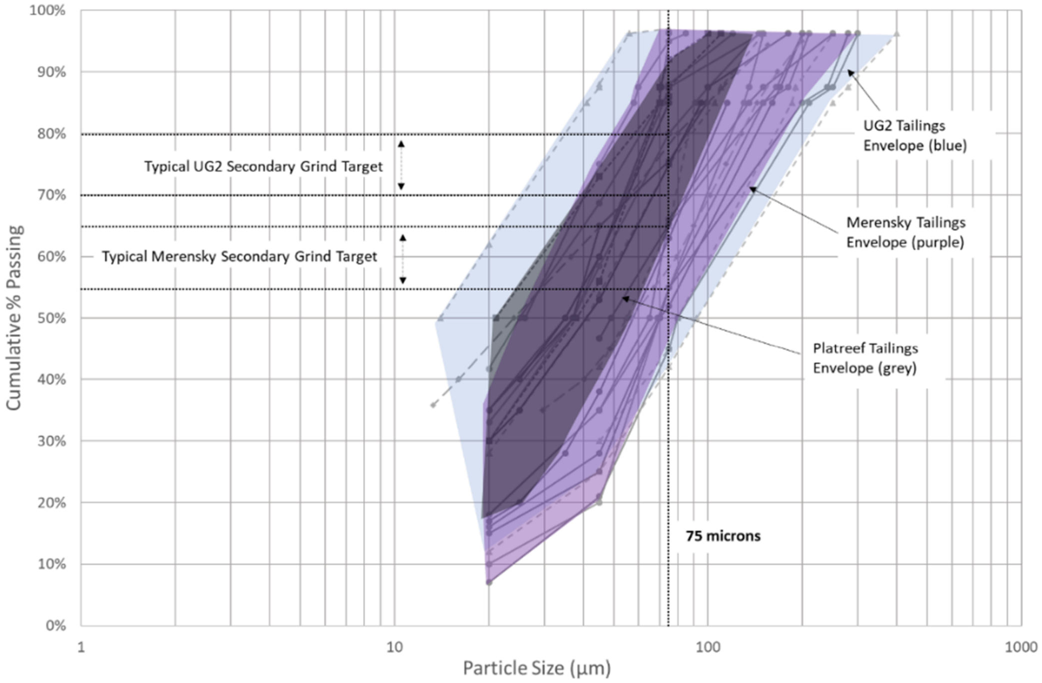


Figure 1 Example of the variation in platinum tailings particle size distribution from different samples for various platinum ores compared with typical secondary grind targets

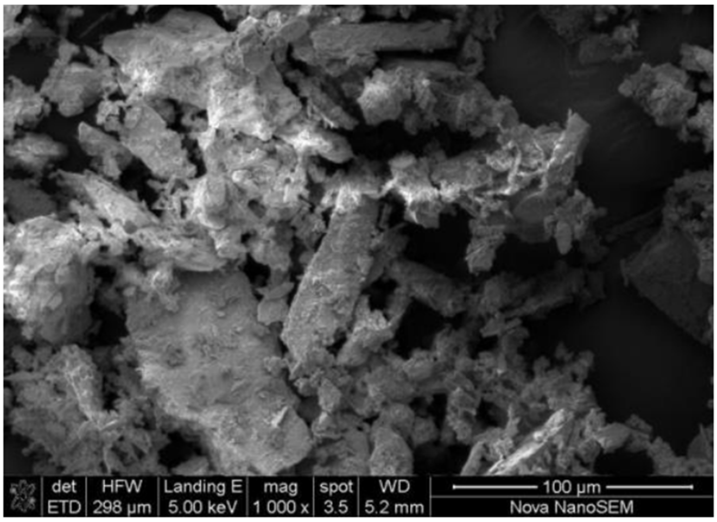


Figure 2 Example of platinum tailings viewed under a scanning electron microscope

3 Dewatering technology

Dewatering technologies available for tailings applications are described in the next section, followed by a discussion of the testwork, design scale-up and the observed performance of the various dewatering technologies when applied to platinum tailings.

3.1 Available technology

Various dewatering technology options are described below. These are: high-rate thickening (typical current practice), paste thickening, vacuum filtration, pressure filtration and other promising technologies currently under investigation. The sections are loosely ordered in terms of decreasing water content in the discharge stream and range from pumpable slurry to dry cake that needs to be transported by truck or conveyor. Figure 3 illustrates the solids concentration achieved by different dewatering technologies compared with the transportation limits for a specific platinum tailings sample tested. Note that every tailings stream will behave slightly differently, depending on the material properties of the slurry.

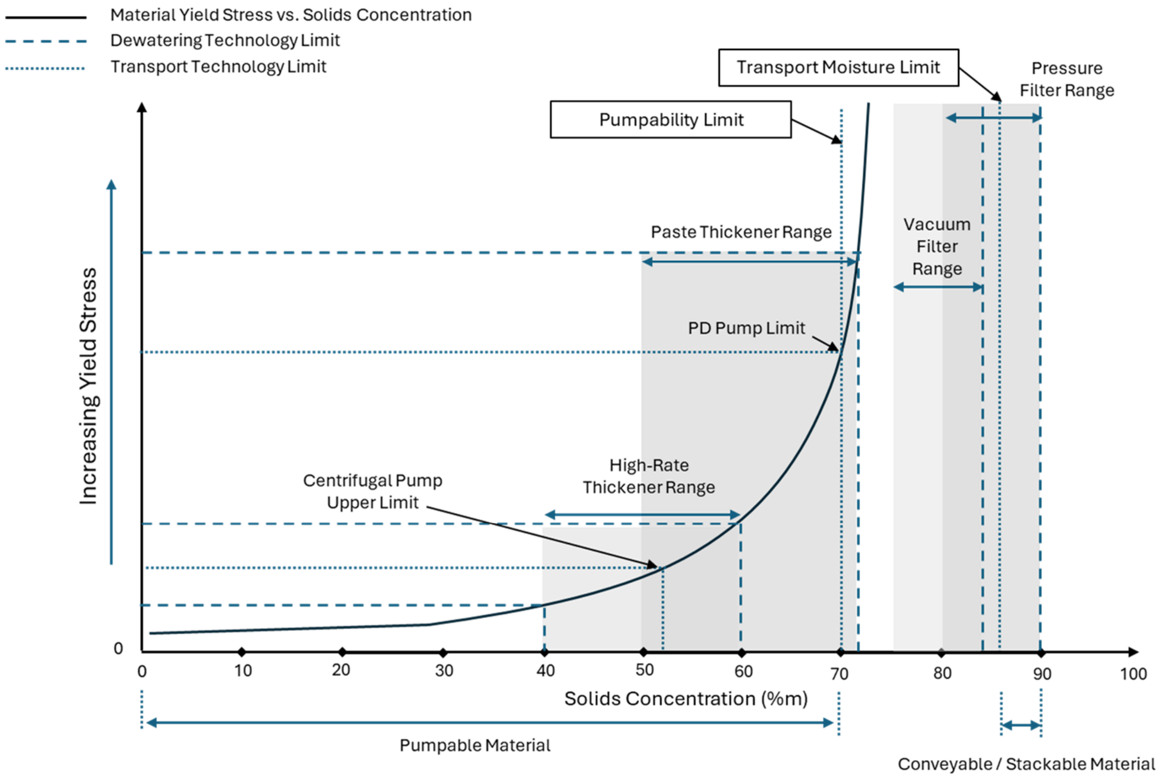


Figure 3 **Solids concentration achieved by different dewatering technologies compared with transportation limits for a specific platinum tailings sample. Values are for illustration only, as each tailings sample needs to be characterised and assessed separately**

3.1.1 High-rate thickening (current practice)

High-rate thickening is commonly used in the platinum industry. The tailings thickening circuit usually includes guard cyclones upstream of the thickener to remove the larger, fast settling fraction that can cause blockages in the thickener. The overflow (fine material) from the guard cyclones reports to the thickener feedwell. The underflow material reports directly to the tailings pump feed tank, where it is mixed with the thickener underflow. The pH is usually neutral to alkaline, sitting in the region of pH 7 to 9, although some high alkalinity slurries have been observed during testwork.

For the purpose of this paper, high-rate thickening is used to refer to flocculated thickeners with shallow cone angles and wall heights of between 2 and 4 m. The rakes may include pickets. High-rate thickeners with higher walls and rake pickets are sometimes categorised separately and referred to as ‘high-density’ thickeners. These thickeners can produce underflow yield stresses of 30 to 50 Pa for typical slurries, depending on the feed material and the design. The underflow slurry yield stresses in the typical operating range of platinum thickeners (45 to 55%m in the underflow) is much lower, with 1.05 to 4.55 Pa reported for slurry concentrations of 49.7 to 59.9%m (Paterson 2004). For low underflow yield stresses, high-rate thickeners can be designed with large diameters (more than 90 m) and high throughputs per unit.

3.1.2 Paste thickening

Paste thickening typically refers to flocculated thickeners that produce underflow with yield stresses up to 100 Pa. These units are designed with wall heights of up to 10 m, a high cone angle and a rake with pickets. The highwall height increases the bed compression, allowing increased water recovery. However, the resultant yield stress also increases the torque required on the rake, which limits the diameter of the unit.

Typical dimensions of a paste thickener are limited to 25 m. Since the throughput of a thickener is limited by the available surface area, the smaller diameter of paste thickeners results in a lower throughput per unit compared to high-rate thickeners (i.e. more units are required to process the same feed).

3.1.3 Vacuum filtration

Two types of vacuum filtration are typically considered in tailings applications: vacuum belt filtration and vacuum disk filtration. Both of these technologies are continuous, but the final solids concentration of the cake is limited by the ability of the vacuum to remove entrained water from the solids.

Vacuum belt filters (Figure 4a) typically consist of a large, horizontal unit with a water-permeable belt. They are similar to a belt feeder, except that the belt is permeable and a vacuum is developed underneath it using a vacuum pump. A combination of the vacuum and gravity drives water through the solids and the belt, resulting in progressively drier material along the length of the belt. Filtered solids are dumped onto a stockpile or conveyor at the end of the vacuum belt filter. Vacuum belt filters can typically be used to form a relatively thick cake compared to vacuum disk filters but can struggle to reach the required solids concentration needed for the transportation and stacking of some tailings.

Vacuum disk filters consist of multiple vertically mounted disks rotating above an agitated tank of the tailings slurry (see Figure 4b). Each disk is separated into segments with an internal vacuum that can be switched on and off at different times in the cycle. Each disk is semi-submerged (typically 30 to 50% of the diameter) and rotates through the slurry. As each segment of the disk rotates through the slurry, the vacuum pulls solids onto the surface of the disk (cake-forming cycle). Once out of the slurry, the cake on the disk segment begins to dry (drying cycle) and is then removed before the segment re-enters the slurry. Vacuum disk filters have the advantage of a very large filtration area per unit footprint (Hahn 2024), however, the short cycle times, thin cake thickness and the solids adherence can limit the effectiveness of this technology for certain applications. There is ongoing development of high-performance vacuum disk filtration technology with the potential to improve solids throughput and the solids content of the cake (Hahn 2024).

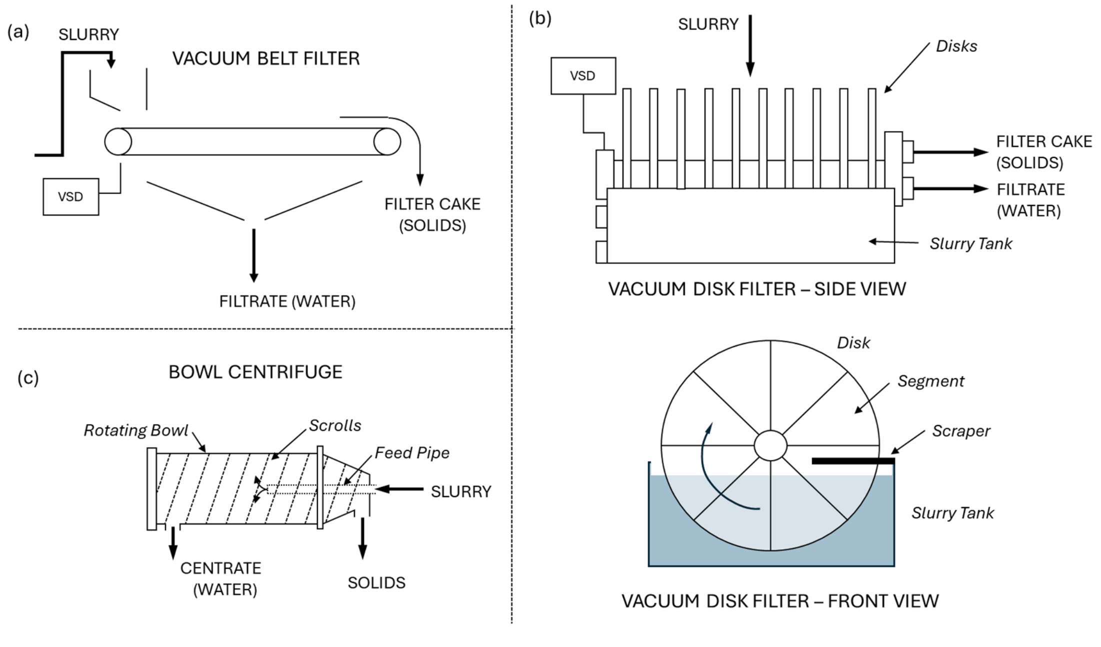


Figure 4 Diagrams of: (a) a vacuum belt filter; (b) a vacuum disk filter; (c) a centrifuge

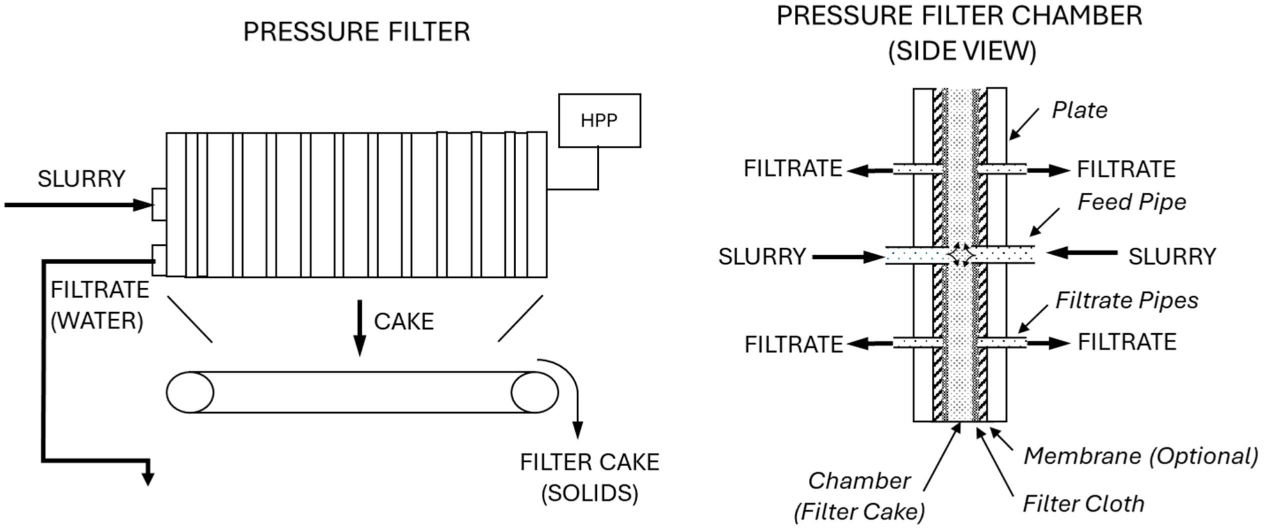
3.1.4 Pressure filtration

Pressure filtration is the dewatering technology that consistently achieves the lowest moisture content. It achieves this by ‘pressing’ the solids against a filter cloth at high pressures. It is also a batch process and, as a result, requires significant additional auxiliary infrastructure, including large filter feed buffer tanks.

Pressure filters are typically built as a plate and frame arrangement, as depicted in Figure 5. The frame supports a number of filter plates which are lined with permeable filter cloth. During filtration the filter press plates are forced together to create multiple chambers which are then filled with slurry (filling cycle) and pressurised for a set period (cake form time) using pumps. On a basic filter, once the cake has been formed, the filter plates are drawn apart and the cake drops out of the filter onto a conveyor or into a loading area. On more sophisticated pressure filters, additional dewatering steps such as membrane squeeze and air blow can be included.

Units with membrane squeeze have a membrane between the filter plate and the filter cloth. At the end of the cake-forming cycle, pressurised air is forced behind the membrane, which expands and presses against the filter cloth and cake. The membrane essentially ‘wrings out’ additional moisture from the cake, further improving the solids concentration of the product.

Units with air blow (also sometimes referred to as ‘cake blow’ or ‘cake drying’) include an additional step in which high volumes of air are forced through the filter cake to achieve further dewatering. The addition of cake drying and membrane squeeze reduces the moisture content of the cake but also increases the cycle time of each filter. A longer cycle time reduces the number of cycles that can be conducted per hour, effectively decreasing the throughput of a single unit. The pressurised air and air blow requirements also add significant opex and capex to the system. The benefits of improved dewatering for each tailings stream need to be carefully considered when selecting the final equipment. For instance, the cost may be justified for a tailings stream for which the transportable moisture limit (TML) cannot be achieved without additional dewatering steps, but it may not be justified for tailings where a basic filter can easily exceed the TML. There is ongoing research and development to improve the throughputs of filter presses and reduce the unit sizes required (Sommacal et al. 2024).



(a) (b)

Figure 5 Diagrams of a horizontal plate and frame pressure filter: (a) side view of the unit; (b) simplified side view section of a pressure filter chamber

3.1.5 Other dewatering technology

Other tailings dewatering technologies that can be considered include continuous centrifuges, screw filters and hydraulic dewatered stacking (HDS).

Dewatering using a solid bowl centrifuge (Figure 4c) involves feeding a flocculated slurry into the centre of the rotating bowl. Centrifugal forces caused by the high-speed rotation fling the solids to the outer rim of the bowl and the scroll then transports the solids to the solids discharge end. Water travels through the centre of the scroll and discharges from the opposite end of the centrifuge. Decanted water from centrifuges is typically a lower clarity (dirtier) than filtrate. Centrifuging also requires flocculation doses that are an order of magnitude higher than standard thickening of the same tailings.

Screw filters are commonly used in pulp and water treatment applications. They are essentially screw feeders which operate against a dead end, compacting all the feed solids and squeezing the water out before dropping the resultant filter cake into a chute. Screw filters are currently being investigated for tailings applications but the authors are not aware of any commercial tailings applications at the time of publishing. A limitation of both screw filters and centrifuges is their per-unit throughput, which is low compared to filters or thickeners.

Coarse flotation technology (Anglo American 2023) has also allowed for the development of HDS, which is currently being trialled. In this system, coarse flotation tailings are placed alternately with fine tailings, facilitating improved dewatering and potentially increasing structural stability.

3.2 Testwork, scale up and performance

Platinum tailings usually perform well across the various dewatering technologies, with test results indicating high solids concentration paste thickener underflows and that tailings can be dewatered past the TML. This provides an opportunity for filtered stacking and also allows for significant gains in water recovery compared to high-rate thickening. However, it has been observed that the performance of the dewatering technology can vary substantially depending on tailings properties, even within the same orebody. The material properties and filtration test results from two Platreef samples with different PSDs and mineralogy are compared in Tables 1 and 2 as an example. The variation in test results demonstrates that it is important representative samples are tested to de-risk the design.

In all scale up and equipment design cases, the design engineer should also consider variability in the tailings feed and the potential for poor feed control, which are typical of tailings thickeners. The sections below discuss testwork requirements, scale up considerations and the observed performance of each dewatering technology.

Table 1 Summary of the material properties of two Platreef samples from different sections of the orebody

Characteristic	**Sample 1**	**Sample 2**
Ore	Platreef	Platreef
Density (kg/m^3)	2,963	3,173
Shape	Angular with some finer, rounded particles	Very angular
Description	Deslimed tailings	Full tailings
pH	8.4	7.1
Conductivity (mS/cm)	19	0.31
% Passing 10 microns	10	20
Transport moisture limit (%m solids)	Not tested	86.7
Major minerals (more than 10%)	–	–
Plagioclase/Enstastite/Augite/Chlorite (%m)	13.4/53.2/11.3/1.8	61.2/0.0/0.0/12.9

Table 2 Excerpt of the filtration test results of two Platreef samples from different sections of the orebody

Characteristic	Sample 1	Sample 2
Slurry feed solids concentration (%m)	60	60
Vacuum (kPa)	75	75
Vacuum belt filter		
Cake solids concentration reported (%m)	81.0–83.5	78.1–80.2
Cake thickness (mm)	6–18	8–15
Vacuum disk filter		
Cake solids concentration reported (%m)	81.0–85.2	66.5–74.7
Cake thickness (mm)	6–15	0.5
Pressure filter with air blow		
Slurry feed solids concentration (%m)	55	50
Feed pressure (kPa)	600	600
Cake solids concentration reported (%m)	87–88.8	86.2–87.9
Cake thickness (mm)	9–17	35–60

3.2.1 High-rate thickening

High-rate thickener performance can be characterised using a combination of static settling tests and benchtop dynamic thickening tests. The static settling tests are used for flocculant screening and can be used for conceptual level sizing. Benchtop dynamic thickening tests are required to predict the full-scale solids flux of the unit and to estimate the expected underflow concentration. If there is a high degree of risk to the project if the desired underflow density is not met, a pilot-scale three-metre-high test rig can be used to predict the underflow solids concentration to a higher degree of accuracy.

The underflow concentration and clarity are dependent on a number of factors, including the flocculant selection, resultant settling rate, solids flux and rise rate in the unit. Generally, underflow concentrations of 55 to 65%m have been observed in benchtop dynamic thickening tests (unpublished data), with a maximum predicted concentration of up to 70%m after 24 hours of consolidation. However, care should be taken when selecting a design underflow for tailings thickeners as it has been noted that in full-scale operation, tailings thickeners often do not perform at the optimum underflow solids concentration observed in benchtop dynamic tests. Reasons for this can include overfeeding, poor flocculation, poor control or limitations on the underflow pumps. Tailings thickener underflow concentrations of 45 to 55%m are typically observed on operating systems (Paterson 2004).

3.2.2 Paste thickening

Scale up of the paste-thickening performance from benchtop tests to full-scale operation is not straightforward. Benchtop dynamic thickening tests can be used to predict full-scale solids flux, however, the bed compression of the full-scale unit cannot be directly correlated to the benchtop test. Testwork on a pilot-scale testing rig is required to predict the full-scale paste thickener underflow concentration for a given residence time (Arbuthnot 2008).

Paste thickening has not been broadly implemented or reported on in the platinum industry. Detailed testwork will be required for an accurate prediction of the underflow density for large-scale installations. Vietti et al. (2010) trialled a pilot-scale paste plant and achieved a 70%m underflow concentration on a Platreef orebody. This is significantly higher than the typical 45 to 55%m concentration observed in full-scale high-rate platinum plant tailings thickeners. It should be noted that the high solids content does not always correspond to paste properties in the underflow. The high-density and settling rate of the solids can cause the underflow to behave as a settling slurry, even at high solids concentrations (Paterson 2004). A potential complication with the design of platinum paste thickeners is the very high consolidated underflow yield stress observed during testwork. This needs to be carefully considered when sizing the rake system, but advances in materials and rake system gearbox design are ongoing and allow for the design of high-torque systems (Kujawa et al. 2019).

3.2.3 Vacuum filtration

Due to the fundamental differences in how vacuum belt filters and vacuum disk filters work (see Section 3.1.3), it is highly recommended that different test methods be used to characterise their performance and quantify the anticipated cake thickness. Scale up from benchtop tests is relatively reliable as long as the sample tested is representative of the final feed material. Care should be taken during the testwork and design of units that will be installed at high altitudes, as this impacts the vacuum strength that can be attained.

The testwork presented in Table 2 shows the vacuum belt filtration results compared with the vacuum disk and pressure filter. Vacuum belt filtration achieved between 78 and 83.5%m solids concentration in the cake of both the full tailings and deslimed tailings sample tested. The cake solids concentration is relatively high compared to other types of tailings tested using similar methods and is a function of the solids density and the tendency of the solids to retain moisture.

Vacuum disk filtration with a feed solids concentration of 60%m is effective for the coarser sample (Sample 1) but not the finer sample (Sample 2). Vacuum disk filter tests on Sample 2 were unable to achieve an effective cake thickness (0.5 mm or less). The reason for the difference is not fully understood, but it is suspected that the shape or rheology of the slurry in Sample 2 may be impacting the ability of the filter cloth to pick the solids up out of an agitated tank. Increasing the thickener underflow density to 70%m can increase the vacuum belt filter cake solids concentration on Sample 2 to 84%m. A paste thickener would be needed to feed the filter such a high density slurry, however, even then, the system could not achieve the required TML of 86.7%m.

The variation in dewatering performances between samples and the inability to meet the TML of the tailings highlight the importance of testing representative samples for each process and application.

3.2.4 Pressure filtration

Benchtop tests can be conducted for early characterisation and equipment sizing. However, if membrane squeeze and air blow are being considered, additional work is required to characterise the tailings performance as the design progresses to more detailed phases. Scaled-up performance is more difficult to predict than for vacuum filters, especially if very large full-scale plates are to be used. However, pilot-scale trials can be considered to reduce the uncertainty of performance on tailings that are difficult to dewater.

The results in Table 2 show excellent discharge cake density in both samples at a solids feed rate of 50 to 55%m. A cake solids concentration of 87 to 88.8%m is achieved for Sample 1, and 86.2 to 87.9%m for Sample 2. This shows that pressure filtration can achieve the required TML of 86.7%m for Sample 2, even using feed from a standard high-rate tailings thickener. The performance can further be improved through the addition of a membrane squeeze step in the final unit or by adjusting the design of the thickener to optimise a higher solids discharge concentration. The filter unit throughput can also be increased by increasing the feed concentration, which reduces the amount of water that needs to be removed and also reduces the cycle time.

3.2.5 Other dewatering technology

The authors have not conducted pilot-scale centrifugation testwork on platinum tailings. However, the reported good filterability, high settling rates and low clay concentration suggest that centrifugation of platinum tailings is worth investigating further. Chinchankar (2024) reports that stackable solids can be obtained using centrifuges and that they are in use in PGM processes. Anglo American has completed greenfield trials at the El Soldado copper mine in Chile (Newman et al. 2023) and is conducting field work on HDS systems at Mogalakwena platinum mine in South Africa (McGregor et al. 2023).

4 The tailings management system as a whole

4.1 The relationship between the dewatering system, transport and the tailings storage facility design

To identify a feasible tailings management system, the available dewatering technologies need to be considered in conjunction with the options for downstream transportation, placement and storage. This requires a thorough understanding of: (1) the material properties required for the storage methods available; and (2) what can be achieved by the dewatering technologies under consideration.

Typically, each tailings management system option is developed by first identifying a TSF design that could be suitable for the site. The selected TSF design then defines the required tailings properties and moisture content of the tailings. Once these are known, tailings dewatering and transportation technologies can be identified (Crystal & Jansen 2024). The process may become iterative if there is no clear-cut solution for a certain TSF design. In these cases, it may be necessary to consider alternative technologies, vary the requirements or else eliminate the option altogether.

4.2 Transport

Three forms of tailings transport are typically considered: slurry transport (usually centrifugal slurry pumps), paste transport (typically piston pumps) and filter cake transport (trucking or conveying). Figure 3 summarises the transport limits for a specific platinum tailings sample and compares it to the dewatering technology ranges.

The pumpability of the tailings, the power needed and the type of pump required are dependent on the slurry properties, the system throughput and the length of the pipeline. Paterson (2004) describes the pumping of typical platinum tailings in detail, including that the high-density of platinum tailings can mean it remains in the settling slurry regime (requiring high transport velocities) at higher mass concentrations than other tailings. Systems can be optimised to minimise opex and capex by considering various pump technologies, placement of the dewatering infrastructure and control of the slurry concentration (Rusconi et al. 2009).

Whether a filter cake can be trucked or conveyed is typically characterised by the TML. The TML defines the moisture limit at which a standard vibration can cause the cake to liquefy and flow. It is important that the cake does not reliquefy for the following reasons: (1) the safety of truck drivers; (2) ease of placement and compaction of the tailings; and (3) effective conveyor transport and placement.

4.3 Placement and tailings storage facility design

The tailings placement methods are dictated by the storage facility design, which is defined by the TSF design team. High-rate thickening is commonly used in the platinum industry to produce tailings used for distributed cycloned or spigotted deposition. Downstream or centreline TSF designs with imported or filtered tailings wall construction can also be considered, but the additional material cost and the inability to progressively rehabilitate the slopes are a downside to these options (Grant-Stewart 2020). To the authors' knowledge, no paste TSFs have been built for platinum tailings in South Africa to date, and they would require a central discharge system and external impoundment walls to contain the slurry. Stacked and filtered tailings need to be placed and compacted using a fleet of mobile equipment. No impoundment is necessary, and the tailings facility is constructed progressively throughout the life of mine. Some designs can also be progressively rehabilitated (Coghill et al. 2024). These factors lower the end of life cost and can also reduce the initial construction cost.

5 Selection of tailings management systems

Once viable tailings management systems have been identified they need to be compared, and the most promising solutions selected for further consideration. Although the technical aspects define what is achievable, the final system will have long-term and broad-reaching social, environmental and economic impacts. These 'softer' aspects are difficult to quantify but also need to be considered during the selection process. The MAA described by the MAC (2021) and MPDEC (2013) aims to provide a traceable, accountable decision-making tool that limits the influence of bias and subjectivity on the outcomes.

5.1 Key drivers

The MAA is usually separated into four main concerns (referred to as 'accounts'): environment, technical, project economics and socio-economics. A panel of experts first divides the accounts into smaller sub-accounts and then assigns a weighting to each. Once this is complete, the panel rates the sub-accounts of each tailings management system. Finally, the overall scores are tallied and compared. The sensitivity of the MAA outcomes may be investigated by varying the weighting of the accounts or sub-accounts (MAC 2021).

Key drivers for the selection of one technology over another typically include risk of failure, maturity of the technology and skills available for design, operation and maintenance. Due to perceived high risks it is often challenging to motivate the adoption of new technology. However, once one operator proves the technology, others will follow.

Project economics of different options are heavily influenced by transportation distances, opex, the life of mine, required throughput and metals prices. They can also be influenced by the legislation, with onerous legislation leading to higher initial costs on certain options. The cash flow required for various options can also play a key role in the selected technology. Copeland et al. (2023) report that a platinum tailings filtered stacking system was selected over a conventional TSF due to the lower capital outlay required.

Environmental key drivers considered include the chemical and physical stability of the tailings (e.g. risk of acid mine drainage or water pollution), as well as any loss of wildlife habitat. Socio-economic drivers typically include the potential for upliftment in the surrounding communities, the location and population density, the economic use of the land at present, and whether it has any cultural, archaeological or religious importance. Given the high levels of unemployment in South Africa, the importance of creating opportunities for sustainable economic upliftment in the platinum belt cannot be overemphasised.

5.2 Areas of improvement

There are a number of aspects that need to be better defined and understood during the high-level trade-offs of alternative tailings systems. Some of these are economic and should be used to enhance our understanding of the true lifecycle cost of TSFs. Aspects that are typically difficult to quantify and poorly reported include the risk of 'new' TSF technology, true closure costs, and the true costs of water, land and financing.

Quantifying the cost of water is particularly difficult because it should ideally include the expected water licence volume and the costs of extraction, transportation or additional processing required for both use and discharge into the environment (Grant-Stewart 2020). South African platinum mines are typically located in areas that are water-scarce on average, but which also have distinct dry and rainy seasons. This means that a mine may have a positive water balance during the rainy season (and need to release water) but a severely negative water balance in the dry season (during which it consumes large amounts of water from external sources). This adds additional complexity to estimating the cost of water management for platinum mines. The water licence volumes granted can have a particularly important influence on the tailings system trade-off as the throughput of the mine can become limited by the raw water supply. In this case, more aggressive dewatering systems can also unlock additional value by providing the water required to increase the throughput of the processing plant (Crystal & Jansen 2024).

Proof of concept of new TSF designs to an acceptable level of risk is also a major hurdle. This requires large-scale trials which are both time-consuming and expensive. The industry is actively working on researching and trialling new TSF designs and technologies (McGregor et. al. 2023; Newman et al. 2023).

6 Conclusion

South African platinum tailings properties are relatively well understood, especially for current operations and laboratory-scale testing of alternative dewatering technologies. However, variations in PSD, mineralogy and test methods can have a significant impact on testwork results. Accurate estimation of full-scale equipment performance relies on appropriated testing being completed on a representative sample of the tailings as the design progresses.

Platinum tailings have been observed to achieve high thickener solids underflow concentrations and attain good filter cake thickness with low levels of moisture content in both vacuum belt and pressure filter laboratory testwork. Even more promising is that the TML has been met for whole tailings using pressure filtration with a standard high-rate thickener feed. Combinations of these dewatering systems can be optimised by considering partial filtration or by increasing the feed density to the filtration plant.

Further development and optimisation of dewatering technology can pave the way to tailings management systems that have not been feasible before. These tailings management systems will hopefully provide mining companies with the opportunity to operate safely, economically and sustainably, thereby maximising benefits to the mine and surrounding communities.

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