Surface Disposal of Past Tailings at the Bulyanhulu Gold Mine, Tanzania

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Abstract

Barrick Gold Corporation's Bulyanhulu Gold Mine in Northern Tanzania was commissioned in the second quarter of 2001. The mine has implemented an innovative total paste solution to tailings management with 25% of the tailings produced by the mill being used underground as blended paste and crushed rock backfill and the remaining 75% being disposed on surface, in a stack, as a paste from end of pipe discharge. A simple, practical definition of paste tailings are tailings that have been dewatered to near the limit of pumpability such they do not segregate during low velocity transport and produce minimal bleed water when deposited.

Surface disposal of paste tailings was chosen for Bulyanhulu because process water is in short supply and natural topography is not available for conventional slurry containment. It was also decided that paste tailings would be used for underground backfill. With paste, water recovery is maximized at the paste plant and recycled to the mill. This method of tailings management simplifies water management, eliminates the requirement to maintain a pond of water on top of the tailings, significantly reduces containment construction, allows for modular expansion of the tailings basin, inhibits oxidation, and facilitates progressive closure as individual components of the tailings basin become exhausted.

The surface deposition plan at the Bulyanhulu site involves the deposition of a stable paste tailings stack using end-of-pipe discharge from multiple deposition towers. Deposition from the towers is cycled to promote consolidation and strength gain of the deposited paste and to control the evolution of the paste stack.

Keywords: tailings, paste, stack, Tanzania, gold mining

Introduction

The Bulyanhulu Gold Mine is located within the Victorian Greenstone Belt in Northern Tanzania, about 50 km south of Lake Victoria and 3 degrees south of the equator. The climate is semi-arid with two distinct rainy seasons that produce short duration, high intensity storms. The annual rainfall is on the order of 1200 mm while annual evaporation is on the order of 1600 mm.

The mine was originally designed for 2,500 tonnes of ore production per day to be processed using gravity and flotation by an onsite mill; however, due to an increase in proven ore reserves it is anticipated that the mining and milling rate will increase. The mine is owned and operated by Kahama Mining Corporation Limited (KMCL), a wholly owned subsidiary of Barrick Gold Corporation.

Golder Paste Technology engineered and designed the distribution systems for surface tailings and underground paste backfill system. Golder Associates planned the surface tailings deposition methods. SNC-Lavalin performed the detailed engineering and construction of the mill and paste production plant.

This paper describes the surface disposal of tailings at Bulyanhulu and reviews the site-specific factors that ultimately led Barrick Gold Corporation to opt for surface disposal of paste tailings at the Bulyanhulu Mine. The paper also reviews the performance of the tailings basin to date and discusses the implication of the findings with respect to developing optimal tailings management practices.

A simple, practical definition of paste tailings is tailings that have been sufficiently dewatered that they do not have a critical flow velocity when pumped, do not segregate when deposited and produce minimal water bleed when discharged from the end of a pipe. The increased viscosity associated with this dewatering also means that paste tailings require positive displacement pumps for pipeline transport; thereby limiting the distance over which paste tailings can be economically transported.

Typically, paste tailings will flow to a slope on the order of 3 to 10 degrees, provided the underlying material has stabilized.

The construction of stack disposal with paste tailings is a natural follow on from depositing tailings as a dense, non-segregating slurry.

Barrick and Golder are strong supporters of university research into the surface disposal of paste tailings. Research into the factors that control the physical and rheologic properties of deposited paste tailings is currently underway at the University of Toronto while research into geochemical and closure considerations of the Bulyanhulu paste stack is underway at Ecole Polytechnique in Montreal. This research will provide value additional insight into optimal management of the paste stack.

Design Objectives

The principal design objectives for the surface paste tailings disposal stack at Bulyanhulu were to:

- conserve water;
- manage runoff;
- minimize containment dam construction;
- reduce risk by not having a pond of water on the tailings surface;
- ensure stability (consolidate the flowing paste by self-weight consolidation and desiccation to inhibit creep under increased height and deformation under seismic loading);
- inhibit the ingress of oxygen and keep saturated to inhibit oxidation (acid generation);
- be accessible to foot traffic and equipment for operation and closure;
- inhibit infiltration to minimize seepage and contaminant transport;
- resist water and wind erosion; and
- facilitate progressive closure.

PASTE TAILINGS GENERATION AND DELIVERY

Generating the paste at Bulyanhulu involves first dewatering the tailings slurry produced in the mill to a filter cake consistency using disk filters. The filter cake is transported, on a conveyor belt, to the paste plant where process water is added in the paste conditioner to produce a paste of the desired consistency. Paste tailings for disposal on surface typically has a 250 mm (10 in) slump (as measured by a standard concrete slump test) at a solids content (by mass) of about 73% (Photo 1). The 250 mm slump represents the approximate limit of paste thickening that can be economically pumped to the tailings basin and dictates the maximum slope angle attainable in the deposition area.

Once the tailings have been mixed to the desired consistency, the paste is pumped with dual piston positive displacement pumps, about 1.6 km to the tailings basin. The non-segregating nature of the paste tailings allows the flow to be stopped in the tailings line for several hours without the need to flush the system.

Tailings Storage Facility

The initial cell of the tailings basin is approximately 780 m long (downslope) by 285 m wide (north south direction), and has five 12 m high deposition towers spaced at 120 m intervals (Figure 1). Perimeter berms are provided to manage runoff. The tailings area has very little topographic relief, sloping about 2% away from the mill area. Deposition towers were initially required to provide elevated discharge points from which the tailings stack could be started (Photo 2). These towers were positioned such that a 12 m high stack flowing to a 10:1 (H:V) slope would just reach the inner toe of the perimeter berm. The surface stack does not rely on natural topography or a dam to contain the tailings.

As is discussed above, the footprint of the initial cell is defined by a 3 m high perimeter berm for the purpose of managing surface runoff. All runoff water is routed through a low-level spillway to a two pond system of primary sedimentation and seepage collection. The ponds have been sized to accommodate the 24-hour duration, 100-year return period storm. This design eliminates the requirement to maintain a pond of water on the tailings surface and thus the risk of a catastrophic failure is greatly reduced or even eliminated.

The flow of tailings to each of the towers can be started and stopped by opening and closing valves on the main tailings distribution line, that is located along the northern perimeter berm of the first cell. A flushing line enables the tailings line to be cleaned between the main tailings line and each deposition tower without the need to flush the entire tailings distribution line all the way back to the paste plant (Photo 3).

Deposition Plan

The behaviour of paste tailings is well documented for use underground; however, there are relatively few precedents on which to base the design of a surface stack of paste tailings. The thickened surface tailings disposal concept, developed by Dr. Eli Robinsky in the early 1970's has been applied at various mining operations for several decades, including the Kidd Creek Mine in Northern Ontario and for managing the disposal of red muds produced by the alumina industry (Robinsky, 1999). However, these operations use non-segregating high-density tailings slurries deposited from a central discharge point that result in beach slope angles typically about 2 degrees. By using higher solids content paste, the typical beach angle can be increased to 10 degrees or more with virtually no runoff water and significantly less shrinkage (Landriault et al, 2001).

Laboratory testing and controlled small scale field testing with the Bulyanhulu tailings indicated that a 250 mm paste slump should translate to a deposited slope angle of about 10:1 (H:V); however, in practice the deposition angle realized in the field can be affected by a wide range of factors including weather conditions, temperature variations and shear effects during pumping, rate of deposition, and the nature of the material upon which the paste is deposited.

Once deposited, the paste will continue to flow until it gains sufficient strength to resist flow (Photo 4). The primary mechanisms for shear strength gain are consolidation (due to self-weight loading) and desiccation (evaporation). Both processes rely on the expulsion of moisture from the tailings mass; however, at Bulyanhulu, desiccation is significantly more effective than self-weight consolidation for generating strength because it happens much quicker.

The tailings for surface disposal at Bulyanhulu are delivered to the tailings basin as a high slump (250 mm) paste and deposited from multiple discharge points (initially towers) as a non-segregating mass with minimal associated bleed water (Photo 5). The paste tailings are deposited in thin layers (maximum 0.3 m) and the deposition is cycled regularly to promote desiccation of the near surface tailings in order to enhance strength gain. This thin layer deposition is the key to strength gain through desiccation. Thick layers do not permit adequate desiccation to stop flows as the stack rises in height. The tailings will flow to the design closure configuration (Photo 6). The side slopes of the deposited stack are to be graded as required to about 10:1 (H:V) for progressive closure.

The Bulyanhulu tailings are known to be potentially acid generating; therefore, progressive closure of exhausted portions of the tailings stack must be implemented in a timely fashion to minimize the potential for long-term, adverse environmental impacts.

Once the tailings stack reaches the top of the deposition towers the tailings deposition will continue by extending the deposition lines to fill topographic lows and to advance the stack to the south (Photo 7). The tailings basin footprint will be expanded in a modular fashion as required. Ongoing deposition will require the main tailings distribution line to be relocated to the top of the tailings and periodically shifted in the direction of advancing deposition in order to facilitate progressive closure of exhausted portions of the tailings stack.

Paste Stack Performance To Date

The paste delivery system has performed well and is capable of delivering a consistent paste product to the disposal area. The generation of the paste stack has proceeded basically as designed and cycling between towers has been successful in generating a stable paste stack provided thin layers are deposited. The average deposited slope angles over the majority of the first cell is in the order of 13.5:1 (H:V), with shallower slopes in areas that have experienced system upsets.

The primary reason for the lower than anticipated deposited slope angles obtained to date is related to prolonged deposition from single discharge points (infrequent rotation of tailings discharge) and thicker than optimal deposited layer thickness – both of which inhibit effective desiccation. The slope angles achieved to date are encouraging, particularly given the challenges associated with commissioning a new tailings facility with a novel concept. It is anticipated that the design 10:1 (H:V) can be attained as the system continues to be optimized.

Sampling of the near surface (upper 3 m) of the deposited paste indicates that the tailings mass is consolidating well and tends to remain close to saturation with an average moisture content (mass water / total mass) of about 24.6% at an average void ratio of about 0.84. The measured moisture content varied between about 22% (for highly desiccated tailings) and 28% (two days after deposition at the surface) versus about 36% immediately after being deposited. Anecdotal evidence, including excavations through the entire deposited thickness of portions of the tailings stack (Photo 8), suggests that there is little or no free water within the deposited tailings mass.

Significant strength gains in the order of 5 to 20 kPa (as measured by field vane) were observed within about five days for thinly deposited tailings; however, these early strength gains were limited to the near surface (upper 30 cm). Thinly deposited paste layers (less than 0.5 m thick) require a minimum of about 3 days for the first desiccation cracks to appear and about 5 days for foot access.

The upper 30 cm to 40 cm of the deposited paste are affected by the daily cycle of the sun (as indicated by tensiometer readings) and it is therefore suggested that deposited layer thickness should be limited to about 30 cm for optimal desiccation. The measured negative porewater pressures in the near surface of a deposited paste layer follow a cyclical (but generally increasing) trend with the maximum observed near surface matric suctions ranging from about 4 to 20 kPa within a few days and in excess of 80 kPa (upper limit of tensiometer) after a few weeks.

Thickly deposited tailings (greater than 1 m in thickness) gain strength slowly at depth (below the influence of the strong evaporative flux) and take longer to develop strength at the surface. The shear strength of thickly deposited tailings was observed to gradually increase to values in excess of 60 kPa, as measured by a field vane, when left to desiccate for a period of several months. Covering a thickly deposited layer of paste tailings with a fresh layer of tailings appears to significantly reduce the rate of strength gain.

Deposition of thick layers of paste tailings also results in deep, wide, desiccation cracks that penetrate the full depth of the layer (Photo 9). These deep desiccation cracks allow increased infiltration of water deep into the stack were it is more likely to contribute to seepage due to limited evaporative flux. Thin layer deposition reduces this problem (Photo 10).

It is interesting to note that areas of the tailings stack that had stabilized to the extent that it could be safely accessed on foot (about 10 kPa vane shear strength) could be completely liquefied ("quickened") to a depth of about 30 cm by repeated rhythmic pumping of the feet for several minutes. This tends to put the tailings into a denser state of packing and the pore water pressure increases thus causing the quickening effect. Once liquefied, a disturbed area was found to demonstrate a significant and rapid strength gain (increase from 10 kPa to 30 kPa) over the following 24 hour period as the induced pore water pressures dissipate. The strength gain was first observed within about 2 hours at the bottom of the zone of disturbance and moved to the surface. Once an area had been consolidated through "quickening", the area could not be re-liquefied through similar rhythmic pumping of the feet because the tailings are now in a denser state of packing. Artificial excitation may prove useful in densifying tailings masses to permit earlier access for equipment and closure, than would otherwise be possible. This phenomenon has been observed in other tailings facilities.

In general, the deposited paste was found to be quite resistant to both erosion and dusting. This is, in part, due to the formation of salt crust (Photo 10). Areas of active deposition and freshly deposited paste (without desiccation cracks) showed negligible erosion potential even during intense rainfall. Desiccated tailings are also quite resistant to erosion and dusting, as the tailings surface tends to develop a crust, which serves to minimize dusting and helps to shed precipitation. Desiccation cracks tend to concentrate flow and minor erosion is evident with older desiccation cracks tending to become rounded and partially infilled (Photo 11). The deposition of fresh tailings effectively fills and seals existing desiccation cracks (Photo 12).

Summary And Conclusions

The surface disposal of paste tailings being discharged from the end of pipe has been successfully applied at Barrick's Bulyanhulu Mine in Northern Tanzania. The Bulyanhulu tailings stack is performing largely as designed and the cycling of the tailings deposition in thin layers has been successful in generating a stable paste stack. Based on early observations, it can be concluded that paste stack can be engineered to meet the required geotechnical and environmental objectives.

As previously mentioned, the desiccated tailings tend to remain near saturation and do not oxidize quickly – however, once disturbed and put into a loose state, the tailings tended to desaturate and the rate of oxidation increases significantly. This is based on visual observations. Early results suggest that thin layer deposition and desiccation is effective in retarding oxidation of the tailings.

At this stage, it is possible to draw some clear conclusions:

- Stacking of paste tailings discharged from the end of pipe is feasible;
- Desiccation is the key to strength gain for the deposited paste;
- The desiccated tailings remain near saturation (minimize oxidation) and are resistant to both erosion and dusting;
- The maximum layer thickness, for optional desiccation is about 30 cm;
- A 5-day deposition cycle seems optimal for adequate desiccation.

Paste tailings deposition at Bulyanhulu offers many advantages over conventional slurried tailings disposal. Early monitoring of the paste stack development has helped to establish the link between operating procedures and observed stack performance. The potential benefits of east (downgradient) optimized tailings management include: improved physical and geochemical performance of the tailings stack, increased storage capacity, reduced tailings footprint, and decreased operating and closure costs.

References

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Photo 1: 250 mm (10 in) slump paste tailings.

Photo 2: Early paste deposition – all towers viewed looking east (downgradient).

Photo 3: Valving along the main tailings line to direct paste and flushing water to individual deposition points.

Photo 4: Three thin layers of paste tailings.

Photo 5: Early paste tailings flow at the start-up of the tailings basin. Note lack of free water.

Photo 6: Progressive paste deposition forming a cone around a deposition tower.

Photo 7: Advancing the tailings deposition with wooden trusses.

Photo 8: Excavation through desiccated tailings.

Photo 9: Wide desiccation crack in thickly deposited tailings layers (about 4 month old deposition).

Photo 10: Thin layer of tailings deposited over heavily desiccated thickly deposited tailings.

Photo 11: Fresh tailing deposited over heavily desiccated tailings (erosion largely due to flushing water).

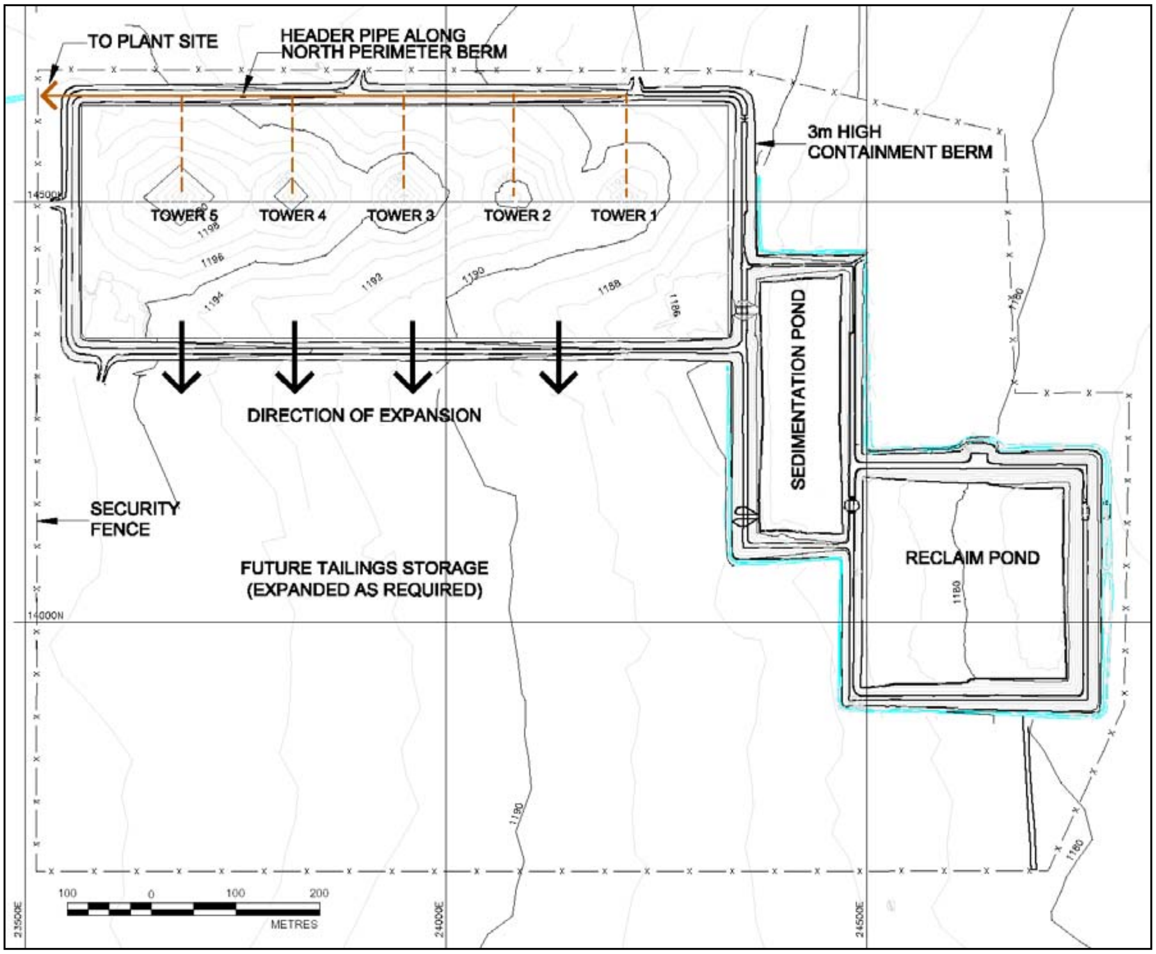

Figure 1: Plan view of "Cell 1" of the Tailings Storage Area showings the direction of future expansion.