Surface Paste Disposal at Bulyanhulu
Practical Lessons Learned

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Abstract

The science and practice of surface disposal of mine tailings with low moisture content is at an early stage of development. Most literature regarding the subject has considered feasibility studies and field trials and conclusions have been drawn from a theoretical base.

The first full-scale implementation of surface paste disposal of gold tailings was initiated at Bulyanhulu Mine operated by Kahama Mining Corporation Ltd in Tanzania. Mine tailings are dewatered by vacuum disc filters and then split between underground and surface disposal. An average of 65,000 tonnes per month are disposed on the surface at an average moisture content of 27% by weight.

This paper describes the experience derived from operation of the surface disposal facility at Bulyanhulu Mine, since commissioning in 2001. The paper focuses on the practical lessons learned with particular reference to tailings preparation, paste pumping, slump measurements, valve operation, tailings placement and geometry control. Aspects of the operation are illustrated with photographs. The paper concludes with recommendations for surface paste disposal that may be useful in guiding further development of this technology.

1. Introduction

1.1. Bulyanhulu Mine

Kahama Mining Corporation Limited (KMCL) is a wholly owned subsidiary of Barrick Gold Corporation. KMCL operates the Bulyanhulu Mine situated in the north west of Tanzania, 50 km south of Lake Victoria. Gold production commenced in 2001 with annual production budget in excess of 350,000 ounces. There are sufficient reserves to ensure a mine life of more than 20 years. The Bulyanhulu Mine is Tanzania's first large-scale underground gold mining investment.

The Bulyanhulu Process Plant treats in excess of one million tonnes per annum using gravity and flotation processes. The entire tailings are filtered and transported as paste, for placement of backfill and deposition at the Tailings Storage Facility (TSF).

1.2. Production of Paste at Bulyanhulu

The entire flotation tailings are thickened to 55 wt% solids in two high rate thickeners. Vacuum disc filters produce a filter cake, which contains 23 wt% moisture. The filtrate is returned to the process plant. The filter cake is conveyed to a paste conditioner, where a small amount of water is added to re-pulp the filter cake to a homogenous paste of approximately 27 wt% moisture.

Approximately 25% of the tailings paste is mixed with aggregate and cement in defined ratios and utilised underground as paste backfill. The remaining paste is pumped to the TSF where it is stacked. Contained moisture evaporates and no water associated with the paste is reclaimed.

At Bulyanhulu, the tailings treatment process is important from an environmental perspective because it consumes less water than conventional tailings disposal.

1.3. Tailings Storage Facility

The Bulyanhulu TSF has been in operation since March 2001. Two positive displacement piston pumps transport the paste 2 km from the paste plant to the TSF. The first cell is approximately 780 m by 285 m. Expansion of the footprint proceeded in 2003 with a second cell of similar dimensions.

Cell 1 and 2 each contain 5 centrally located vertical towers of 12 m height. The perimeter berm around the cells is 3 m high. Storm water runoff from the tailings facility surface is routed to the sedimentation pond and discharged to the water reclaim pond. The TSF presently comprises two cells and covers an area of approximately 65 hectares. Figure 1 illustrates the five towers on Cell 2. Figure 2 shows the layout plan of the TSF; the location of Cell 1 and Cell 2, the central towers and the sedimentation and water reclaim ponds.

When the footprint was expanded, a second tailings pipeline was also added. This resulted in each tailings disposal pump having a dedicated pipe for paste delivery to the tailings facility. The second pipeline and tailings cell was commissioned in August 2003. The second tailings line enabled increased mass flow of tailings to the TSF as the two disposal pumps deliver tailings to both cells simultaneously.

Figure 1: Five towers on TSF Cell 2, commissioned in August 2003.

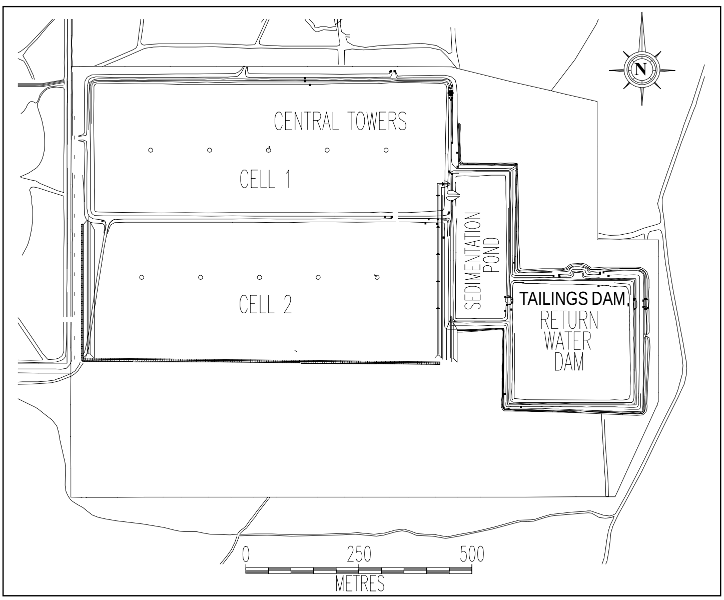

Figure 2: Layout of the Bulyanhulu Tailings Storage Facility.

1.4. Benefits of Surface Paste Disposal

Significant cost and environmental advantages are possible through utilisation of surface disposal of mine tailings at low moisture content. Compared to conventional tailings facilities, these advantages include:

- Water recycled to the process plant is maximised prior to tailings deposition.
- Reduced risk of TSF embankment failure as paste is stable after deposition and not likely to liquefy.

- Low water seepage to the environment.
- Minimum access time onto the tailings surface.
- Increased storage capacity of the tailings facility footprint.
- The stability of the paste reduces the costs associated with construction of a conventional tailings dam.
- Progressive reclamation of the tailings facility can commence whilst it is still operational.

2. Characteristics of Paste Tailings

2.1. Paste Slump

Paste at Bulyanhulu is produced with a typical slump of 238 to 250 mm with very minimal water bleed. Slump is measured by a conventional slump cone test.

2.2. Paste Pumping

Several towers on each cell are up to 500 m further from the paste plant than the closest towers. Also, paste pumped to towers on Cell 2 travels an additional 500 m from the paste plant than adjacent towers on Cell 1. The additional distance to the furthest towers requires production of a paste of higher slump in order to reduce line friction losses and maintain the hydraulic pressures within the operational parameters of the pumps. Thinner paste is produced for the furthest towers with a slump of 250 to 263 mm, compared to the target paste slump of 238 mm.

It is recognized that lower slump tailings (lower moisture content) will desiccate quicker, produce less water bleed and allow for more flexible operating practices. Paste of higher moisture content forms a lower beach angle. The paste deposited at the furthest towers therefore has a different geometry to that deposited at the towers closest to the paste plant.

Subsequent to August 2003 it became possible to operate both tailings disposal pumps simultaneously to a tower on each cell. This enabled the two pumps to be operated at a lower speed to deliver paste at the further towers at a lower slump. This assisted in achieving an increased beach angle. Prior to August 2003, one pump would be operating close to maximum output to maintain the required throughput.

Experience to date indicates that the technical limit to pumping the Bulyanhulu paste tailings to the TSF is 238 mm slump as measured at the tailings pumps. The observed slump at the deposition point tends to be higher, due to shear thinning and temperature effects. For example, a paste produced at the plant with a slump of 250 mm thins to a slump of approximately 263 mm at the point of discharge.

2.3. Paste Stability

The deposited paste continues to flow until it gains sufficient strength, either by consolidation, desiccation or if it encounters a physical barrier. The paste dries rapidly due to high evaporation rates of around 1,600 mm/yr. When the surface remains undisturbed for a period of time, the process of desiccation forms a crust on the exposed tailings. This appears to act as a surface binder that inhibits the onset of oxidisation and dust generation.

The time period required to gain access is dependent on the layer depth. Thin paste layers are dry enough to withstand the weight of a person within 24 hours of deposition and within one week it is possible to move freely over the deposited paste.

After one month the paste is stable enough to support a light vehicle without rutting. This facilitates ease of movement over the surface and enables the transport of wood and pipes required for tower extensions. Vehicle access onto the tailings facility is however controlled to avoid breaking the surface crust and inducing erosion and dust generation.

2.4. Desiccation Cracks

As the moisture from the deposited paste evaporates, desiccation cracks form. Thinner layers develop closer spaced desiccation cracks compared to layers over 0.3 m. When successive layers of paste are deposited over previous layers, the cracks are filled with the fresh paste. This seals the layer below from further oxidation and water percolation. Figure 3 illustrates typical desiccation cracks on the surface paste layer.

Figure 3: Desiccation cracks on surface.

2.5. Crust Formation on Disturbed Tailings

Tailings that are disturbed and left in a loose state tend to oxidise rapidly. Observation of the disturbed tailings however shows that the total production of salts does not differ greatly from the undisturbed beach surface and that a stable crust forms on the disturbed tailings after one wet season, protecting the layers below from further oxidation. After several wet seasons the crust capping hardens further and becomes an oxidised red-brown colour. Tailings crusted in this manner have good strength, indicating suitability for building berms and embankments contained within the TSF footprint.

3. Management of Surface Tailings Disposal

The science and practice of surface disposal of tailings with low moisture content is at an early stage of development. Since operation of the Bulyanhulu TSF commenced in March 2001, some interesting challenges have been encountered. This has resulted in several phases of operational modifications and practical lessons learned.

3.1. Deposition Cycle and Paste Depth

The deposition plan is based on building a stable stack from multiple deposition points. Several parameters must be considered and closely monitored when managing the deposition cycle. These include; depth of the paste layer, consolidation strength gain, paste drying times, freeboard at the perimeter berm, beach angles and general topography of the tailings facility.

Topographic lows must be filled with paste to prevent pooling of water on the surface of the tailings facility. Controlling the direction of paste discharge is important to achieve this, and is discussed later in the paper.

Changing deposition towers on a frequent basis produces thinner paste layers. Thinner layers generally form a steeper beach angle. A typical slope is 1 in 12 for layers around 0.3 m, and a slope of 1 in 14 for layers up to 1.0 m. Increasing the beach angle is advantageous as it enables a higher stacking volume on the same footprint. Experience to date suggests that a layer thickness of 0.3 m is appropriate to facilitate desiccation and associated strength gain.

Whilst there are benefits to frequently changing deposition towers, management of the deposition cycle must consider the increased oxidation rates for thin layers. Thin layers facilitate steeper beach angles, however at the same time the tailings dry faster thus increasing oxidation of the surface. Saline precipitates form on the surface as the tailings dries. During the years of operation at Bulyanhulu, the effect of surface salts on reducing the pH of runoff water has been observed, and determined to be directly related to historical tower changing strategies.

The objective is to cycle deposition from the towers to maintain the desired beach angle without causing salt formation on large areas of the tailings facility. In addition, the surface topography of the facility must encourage water runoff to the sedimentation pond and prevent water pooling.

Research is being conducted to determine the optimum layer thickness and tower changing schedule that will maintain an adequate beach slope whilst minimising effects of surface oxidation and acid generating properties of the tailings surface.

Figure 4: End of pipe discharge from a vertical pipe.

3.2. Deposition of Paste from the Tower – Geometry Control

There have been several stages of development of discharge techniques at the paste deposition point. The original towers were 12 m vertical pipes from which paste simply discharged from the end of pipe. This was designed to provide the elevation to permit tailings to be stacked to the proposed 12 m height and allow the area surrounding the tower to start to beach. This strategy was effective for initial stages of deposition however it offered no control over the direction of the paste flow once a beach angle developed. This deposition method impacted the manageability of the TSF. Figure 4 illustrates end of pipe discharge from a vertical pipe.

In an effort to encourage directional paste flow, horizontal arms were added to the top of the pipe that could be rotated and pointed in the desired direction. This method was further improved by extending the lengths of pipe and supporting the pipe on wooden towers. These tower extensions were increased in length up to 30 m from the original vertical tower deposition point. The tower extensions were effective in directing the paste to the desired area however were time-consuming to build. The wooden support towers have to be regularly maintained and the appearance of these towers is unsightly. The horizontal tower extensions are illustrated in Figure 5.

A new method was trialed in late 2003 whereby the paste itself supports the discharge pipe. ‘Finger dykes’ are created by allowing paste to build up around the discharge pipe eventually submerging the pipe, which results in mounding. This mound of paste is used to support the next horizontal pipe extension. The advancing end of the pipe position creates adjacent mounding, ultimately forming a ‘finger’ shaped dyke. As the ridge is slowly ‘walked’ across the tailings surface, valleys are created between the towers. These are easily filled by guiding the paste into the hollow areas. Figure 6 illustrates a finger dyke, where the pipe is supported on the paste mounds.

Pipe extensions along finger dykes are a practical choice as the paste stabilises quickly and provides safe access to the deposition point. Successful implementation of this method also eliminates the use of unsightly wooden support towers.

3.3. Control of Paste Discharge Direction

Learning to control the direction of paste flow once it has discharged from the end of pipe has been an important development in managing the Bulyanhulu TSF. Directing the paste flow towards the topographic lows of the tailings stack is of particular importance.

Wooden barricades have been used with some success to direct the flow of discharging paste, however they are time consuming to construct and maintain, appear unsightly and paste can divert around and under the barricade.

Figure 5: Horizontal tower extension, with wooden support tower.

Figure 6: A 'finger dyke' supports the discharge pipe.

A new method of controlling the flow direction of discharging paste was developed in late 2003. Water is pumped through the tailings pipe and directed to shape a channel towards the required point on the tailings surface. Once the channel has formed the paste is pumped to the tower and directed through the channel to the required area. The water used to make the channel evaporates or reports to the sedimentation pond. The ability to control the direction of paste flow using this technique has improved the manageability of surface geometry without the need to overuse wooden barricades. Figure 7 illustrates paste being directed through a water-formed channel.

Figure 7: Paste is directed down a water-formed channel to the desired area of deposition.

3.4. Flow Characteristics of Paste

Once the stack has gained initial height at the point of deposition, a channeled flow from the pipe is maintained. These channels are manipulated by the use of water and/or small barricades to redirect the flow to the desired area of deposition.

True sheet flow is not observed during operation, but rather the flow is comprised of several smaller channeled flows that change direction as the resistance down one channel increases. This spreads the paste over a large area and appears to have sheet flow characteristics. Figure 8 illustrates the sheet flow characteristics of paste further down the beach.

Another interesting observation results from the paste surging with each stroke of the positive displacement pump. When the paste flows in a channel this action slowly increases the height of the paste on either side of the channel. If the paste is deposited in this state at any single location for longer than one month, the ridges on either side of the main flow can start to close over or encase the main flow of paste. The resultant visual effect is that the paste is flowing very slowly, however most of the paste is flowing under the surface of the encasement capping and the true flow of paste is only observed when the paste starts to spread over a large area further down the beach.

It has also been observed on rare occasions that the paste can flow in a complete subterranean tube whereby the flow is not observed on the surface for up to 100 m before resurfacing at a lower area on the beach. This has occurred when barricades have been erected to redirect the paste flow. Whilst a fraction of the paste is visually diverted in the desired direction, the remainder of the paste flows under the barricade. As the rate of paste flow down the original channel reduces, it provides the surface of the channel time to harden, forming a paste tube below the surface. On several occasions the entire flow of paste, that is 80 m^3/hr, has flowed through a subterranean tube.

3.5. Water Runoff and Management

The water management philosophy is to keep water runoff from the TSF separate from the surrounding environment. To this end, water from the environment is diverted away from the TSF by a series of cut-off trenches. Water falling on the TSF is contained and reclaimed.

The paste surface has relatively low permeability due to the consolidated solids and protective surface crust. During rainstorms water runoff from the tailings surface is estimated at 80 to 90%. Annual rainfall is typically 1,000 mm falling in two distinct wet seasons. The large surface area of the tailings facility and high proportion of runoff causes high rates of storm water accumulation during wet seasons. Storm water runoff is routed into the sedimentation pond via a spillway and discharged into the reclaim water pond for use at the process plant.

Figure 8: Sheet flow characteristics of paste, after initial channel flow.

The TSF must be monitored closely and well managed due to the acid generation potential of the tailings. Water collected on the tailings surface must be channeled directly to the sedimentation pond and not be permitted to pool on the surface of the facility. If allowed to pool, the pH of water on the tailings surface can decrease to below pH 4.0.

Construction of the second tailings cell more than doubled the collection area for storm water and the quantity collected through 2004 was higher than previous years. Actions initiated to reduce collected water included diversions of water that had not come into contact with the tailings, evaporation sprays and review of the site water balance and water management.

3.6. Tailings Facility Valves

The original valves installed on Cell 1 were enclosed knife gate valves. Paste deposited and solidified above the knife blade, which caused the valve to jam open or closed. It would take three personnel three hours to change deposition towers in the early years of operation as valves had to be dismantled and unblocked. Valves were continually replaced due to damaged gearboxes or knife gates. Inability to change valves efficiently resulted in deposition from a single tower for several months at one time. This affected management of the deposition cycle, and factors such as deposition depth, geometry control, surface salt formation and access onto the tailings surface could not be controlled effectively. In November 2002, a flushing system that flushed the actual valve itself replaced the previously inadequate system. This reduced the valve changeover time to thirty minutes.

In 2003, the valve and flushing system was redesigned for the second tailings cell expansion. A hydraulic pinch valve was installed on the paste line for each tower. This reduced the time to change deposition towers to five minutes. This success resulted in a replacement plan for the original valves on Cell 1. Figure 9 illustrates the hydraulic pinch valves and flushing system installed on Cell 2.

The hydraulic pinch valves on Cell 2 functioned well when operating the towers closest to the paste plant. However, as the pumping distance increased to the furthest two towers on Cell 2, the pressure increased against the closed valves at the closest towers. Hammer in the line from the positive displacement pump compounded the forces at the valve and resulted in several failures of the valve at the closest tower. The failure mechanism is snapping of bolts that clamp the hydraulic cylinder onto the pinch valve assembly. The condition is currently being investigated for a permanent solution.

Figure 9: Hydraulic pinch valves and flushing system.

3.7. Storage Capacity Expansion

The original deposition plan called for the tailings header to be moved to the top of the paste stack as soon as deposition from the five towers on Cell 1 had reached full height of 12 m. However, it has been found possible to continue using the existing tailings lines by continuing to move the discharge point using the 'finger dyke' technique. This strategy is working well for accessing additional storage capacity, filling topographical lows and advancing the paste stack.

At the current rate of deposition, it will be necessary to expand the TSF within the next two years. Cost of footprint expansion is substantial and the volume of storm water run off increases as the size of the footprint increases. Options to raise the perimeter of the tailings facility to increase storage space and delay further lateral expansion are under investigation. The facility perimeter can be raised by as much as 20 m above ground level which will extend the life of the two operative cells to approximately six years.

There are economical advantages in using tailings to raise the perimeter. The formation of a stable crust on disturbed tailings has been discussed. Compacting and sealing the upper layer of disturbed tailings used to construct the embankment is likely to reduce oxidation further. In addition, research is being conducted to investigate appropriate material and vegetation cover to prevent erosion damage on perimeter walls constructed from tailings. The performance of tailings to raise the perimeter embankment will be assessed in the field through 2005.

4. Conclusion

The Tailings Storage Facility at Bulyanhulu has been operational for almost four years. In this time much has been learnt about the practical aspects of operation. The key lessons learned are outlined below.

It is important to control deposition in order to limit the layer thickness to approximately 0.3 m, whilst maintaining a frequent cycle time to prevent excessive drying of the surface. It is essential to be able to change valves efficiently to achieve this.

Control of surface geometry is important in order to limit pooling of storm water and to ensure that freeboard is maintained at the perimeter berm. Surface geometry is controlled by directing paste to the required area. This is achieved effectively by using ‘finger dykes’ and discharging paste through channels as described in the paper.

Storm water management is important. The volume of storm water collected from the TSF must be minimised by keeping the operating footprint as small as possible. This can be achieved by raising the perimeter and by concurrent reclamation.

Many innovative ideas have been applied to deal with the interesting challenges of surface paste disposal. New operational ideas and field trials will be integrated with ongoing research and test work to further advance the techniques for management of the Bulyanhulu TSF in future.