Mine Fill 2014 – Y Potvin and AG Grice (eds)
© 2014 Australian Centre for Geomechanics, Perth, ISBN 978-0-9870937-8-3
doi:10.36487/ACG_rep/1404_16_Revell

Producing paste from all materials

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Abstract

Paste fill continues to become a more popular filling method as orebodies become deeper and higher extraction ratios are desired. As it becomes more popular, the range of material used to produce paste fill continues to grow. As a result, the design challenges in constructing plants using this variable material become increasingly difficult. This paper presents a series of different paste fill system designs that have been implemented over the past five years primarily in Australia. The systems include the latest designs in producing paste fill from 'wet' tailings, to using both easy and difficult to handle reclaimed tailings from tailings storage facilities to a fully mobile system producing paste from alluvial clays and aggregates. The design philosophies are discussed along with the innovative techniques used to suit the materials available. Subsequently the successes and challenges of each of the operations are discussed and the resulting changes that will be adopted for the next generation of paste plants.

1 Introduction

When paste was first introduced in Germany and then more widely in Canada in the 1990s it was generally produced using tailings direct from ore processing or what is referred to herein as 'wet' tailings. Thickeners and disc filters were generally used to dewater the tailings before mixing with a cementitious binder and water to produce a flowable material. Whilst this process route is still common today, due to the many advantages of paste as a fill medium, it is being produced from a much wider range of feed materials and process techniques.

This paper presents a series of paste fill systems that have been implemented over the past five years in Australia. While this paper presents one paste fill system using wet tailings, the major focus is on fill systems using reclaimed material. In most cases the reclaimed material is moist tailings from decommissioned surface tailings storage facilities (TSF), and in one case, surface alluvial material. Reclaimed material paste systems have become prevalent in Australia as some mines have either no access to wet tailings or a reclaimed paste system presents a much lower capital investment. Due to the wide range of reclaimed material properties, there are often significant design and operational challenges. This paper outlines challenges encountered in a number of operational paste fill systems.

2 Golden rules

Regardless of the feed material or location of the plant all the paste system designs presented in this paper follow four golden rules.

1. A holistic design approach is followed; meaning the plant is designed considering the entire mine operation and what adds the most value to the operation. Within the paste system battery limits the design considers the plant, underground pipe reticulation system and the in-stope properties required.
2. The plant is designed to suit the materials and not vice versa. Experience has shown that trying to modify the feed materials to suit a standard plant has a much higher cost outcome.
3. Weight measurement and control is required on all solid feed materials. The use of volumetric feed systems is not included on any designs. Weight systems provide high levels of accuracy and most critically continue to operate as the plant ages and do not rely on regular operator inspections. A common issue with volumetric feeders on tailings feed systems is they do not

identify if the feed opening becomes partially blocked. This either results in poor quality paste or significant risk of underground pipe blockage. Generally the highest accuracy weight systems are installed. However, on some occasions weight measurement accuracy is compromised in order to provide a more robust and lower maintenance system.

4. The plants are designed to deliver quality paste. Within the industry, quality paste means the solids content of the paste is maximised. Figure 1 below shows a typical chart of unconfined compressive strength (UCS) versus hydration time for pastes of different rheology and solids content (to achieve a lower slump the paste solids content is increased). It can be seen that significantly higher strengths are achieved by reducing the slump. Therefore the operational strategy is to deliver the highest solids content/lowest slump possible which allows the binder content to be optimised and minimises pipe wear from any free fall on the underground reticulation system.

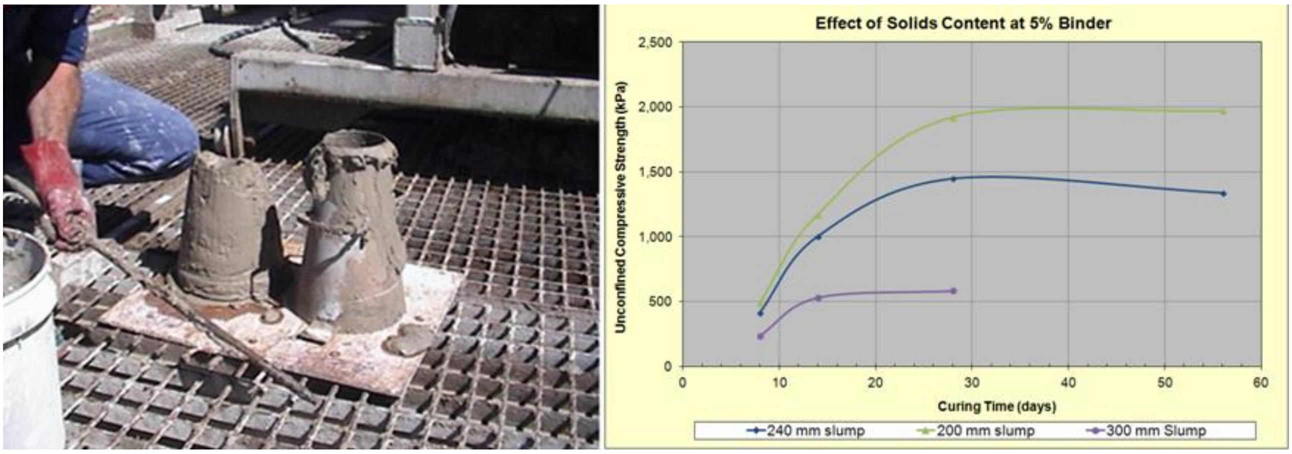

Figure 1 Quality paste

3 Reclaimed tailings paste systems

This section of the paper presents case studies on five different paste operations with the design of each of these systems developed to suit the different feed material.

3.1 Western Areas Spotted Quoll

The paste fill system at Spotted Quoll is the most traditional of reclaimed tailings systems. The plant is effectively the fourth iteration of this paste fill system design and thus incorporates all of the learnings of the similar designs that have come before it. The Spotted Quoll plant is characterised by the tailings being excavated from a TSF that has been decommissioned for many years. The tailings are relatively dry and friable. In more recent times, the tailings have been combined with high quality dune sand. Figure 2 shows the dune sand in the background, two stockpiles of tailings and the blended tailings and sand in the foreground.

Figure 2 Spotted Quoll paste feed material stockpiles

In order to remove foreign material and break up consolidated lumps of tailings, the material is screened using a mobile integrated screening unit (MISU) fitted to an excavator. The MISU uses a spinning rotor system to screen the material and will also crush the softer consolidated tailings. This method of screening has proven very successful and cost-effective on tailings as it is able to handle very moist material and also the amount of oversize is limited since the lumps of tailings are crushed.

Figure 3 Mobile integrated screening unit (MISU)

Figure 4 shows the Spotted Quoll paste plant. The plant is designed to produce 130 m^3/h of paste. The plant consists of a material feed hopper, belt feeder, inclined conveyor, continuous twin shaft mixer, binder silo and metering system. This plant design is relatively simple, compact, very robust and moderately low cost. It is built on steeply sloping floors and has full access to all components, maximising ease of maintenance. Regardless of the plant type, producing paste is generally a messy business and good access with the ability to easily clean the plant is critical to ensure the ongoing operability.

Figure 4 Spotted Quoll paste plant

The critical design aspects of the Spotted Quoll plant are:

- The tailings feed hopper is wide and long and completely lined with ultra high molecular weight polyethylene (UHMWPE). This ensures even relatively moist material can be fed into and out of the hopper without hang-ups. The large, wide and long opening requires a relatively high power belt feeder drive. At a number of different sites over the years, second hand plants from the civil industry have been used to produce paste fill. These civil style plants generally have narrow feeders that are suited to free flowing sand and aggregates. The result is that the moist tailings do not discharge evenly from the hopper. If the control system is not perfect, the general outcome is a slug of very thick/high yield stress paste being produced, often resulting in a blocked underground piping system.
- A variable speed belt feeder and feedback control system using a weightometer on the inclined feed belt. The inclined feed belt is well suited to the moist tailings with little or no spillage and the weight feedback is critical.

- The inclined conveyor is wider than the belt feeder eliminating any material transfer issues between the feeder and conveyor that could occur when treating high moisture material.
- A twin shaft mixer is employed on this plant.
- A loss in weight (LIW) binder system. The system at Spotted Quoll consists of a weight hopper and variable speed auger. The entire system is housed in cladding to minimise disturbance from wind. This binder addition system provides moderate accuracy. The disadvantages of the LIW system is that the binder addition is only partially controlled when the binder weigh hopper is being refilled and also the screw auger does not provide constant output for a given speed. These downsides are well recognised, however the key advantage of this system is it requires almost no maintenance and takes up limited height resulting in reduced capital expenditure.
- The mixed paste is discharged over a 50 mm aperture vibrating screen to capture any foreign material and reduce the risk of an underground pipe system blockage. The paste level is controlled in the paste hopper to ensure the piping system is maintained under vacuum and allows very high solids content paste to be discharged underground. The control valve is a high quality pinch valve which has proven hugely successful on plants in the last few years and can handle full vacuum conditions.

The other key aspect of the plant is the control system. The plant has a highly advanced control system, with significant levels of in-built protection and alarm capabilities. Furthermore, underground instrumentation data is returned to the paste plant allowing the operators to optimise management of the underground piping system and maximise paste quality in real time. The plant also has a complete laboratory on the same level as the paste mixer where samples are taken. This allows the operators to complete all quality control activities on the paste which is key to generating a quality paste culture on site.

The Spotted Quoll paste system was commissioned extremely quickly in mid 2012 and has been very successful. This of course is expected in a plant design that is an evolution of a number of similar previous designs. In addition as we like to say in our operating group, if the feed material is good then it is easy to produce high quality paste.

The only real issue experienced on the system in the first three months of operation was a high quantity of rocks that made it into tailings feed hopper. As a critical learning, it is crucial that robust systems and procedures are in place to prevent large rocks from entering the paste plant. The rocks tend to block the outlet of the tailings hopper and also can cause significant damage to the paste mixer.

The inability to completely ensure rocks do not enter the process is one of the key design challenges in this type of plant. Accepting that human mistakes will occur, the twin shaft mixer used in these types of plants is derived from the concrete industry. A number of modifications are made to this mixer, however it is still only able to provide moderate mixing and the maintenance and cleaning required is still moderate. The advantage though is that this type of mixer is extremely robust and can handle foreign material. Other sludge style mixers would provide improved mixing, however, they cannot handle some amount of foreign material. As a result, for future plants more significant design changes are being implemented to produce a true paste mixer. However, the mixer will always be compromised to prevent catastrophic damage when the inevitable rock or foreign material passes through the plant.

3.2 Newmont Tanami and Glencore Lady Loretta

The Newmont Tanami and Lady Loretta plant is very similar in concept to Spotted Quoll, however it includes an inline screening unit and also produces up to 200 m^3/h of paste fill. Following commissioning, over 17 months, 1.6 m t of paste was produced to catch up on the backlog of voids and as a result the paste system has been seen as a great success.

Figure 5 Newmont Tanami paste plant

The system design at Newmont Tanami includes a belt feeder and inclined conveyor feeding a twin deck vibrating screen. The screen undersize passes into a second storage hopper whilst the screen oversize is discharged. From this point the tailings feed and mixing is very similar to Spotted Quoll.

For the binder in this system one of two 300 t silos feed into a small 1.5 t loss in weight calibration hopper. From this hopper originally a single screw auger fed into a Schenck continuous mass flow meter. Whilst the accuracy of the Schenck units was well documented in the cement industry, there was uncertainty about its reliability especially in a dusty and extremely remote mine site. However, the unit has operated with minimal maintenance. The key advantage of the Schenck unit is that it is both very accurate and continuous. So unlike a loss in weight feeder, there is never any time when the binder is not being measured and controlled. It is highlighted the loss in weight unit above the Schenck mass flow meter is not used in control, but rather provides a continuous calibration check on the Schenck unit.

The only challenge of the binder system came with the feed auger. Even at the extreme angle shown in Figure 6 the binder would fluidise from the loss in weight hopper during the fill cycle and flow in an uncontrolled way through the screw auger. The system was easily fixed through installation of a rotary valve above the screw auger as shown in Figure 6.

Figure 6 Newmont Tanami binder metering system

The main issue at the plant is the mixer has required a relatively high level of maintenance. One of the key issues with the twin shaft mixers is the seals tend to fail at the discharge end due to material splashing onto the back wall and then running out along the shaft. With good maintenance this can be managed, however often there is significant production pressure such that the seals are not fixed in a timely manner and paste migrates into the bearings and even the gearbox in extreme situations.

Figure 4 shows the Lady Loretta paste plant which was commissioned in early 2013. This is a similar design to Newmont Tanami with the following key design changes/improvements:

- The first tailings hopper is rotated through 90°. As part of all designs, the hopper is aligned to prevent the loader driver facing the rising or setting sun.
- On Newmont Tanami the tailings feed hopper was fitted with grizzly bars to eliminate oversize material entering the plant (plus 100 mm). One of the issues with the Newmont Tanami design is the oversize material must then be scraped back onto the ramp and removed by the loader. At Lady Loretta the grizzly was sloped the opposite direction so all oversize would discharge into a bunker on the opposite side to the loader. However even with wide spaced grizzly bars (150 mm), the moist tailings bridges over the bars and cannot be reached by the loader. As a result, a design improvement is underway to improve this scenario, although the simplistic method of using the loader may be a more suitable future design technique.
- A major design change on the Lady Loretta plant compared to Newmont Tanami is that the binder system contains a loss in weight binder system. Binder from existing 1,000 t silos is transferred pneumatically into a disentrainment hopper. The binder is then discharged via a rotary valve into

a large loss in weight hopper. The binder is subsequently metered into the mixer via a variable speed rotary valve. As with Spotted Quoll the loss in weight system is fully protected from the wind. One of the unique design innovations is the loss in weight hopper is fitted with a set of mounts whereby a measured load can be placed onto the loss in weight hopper. This makes ongoing calibration of the binder system simple and easy.

- Lady Loretta also includes a twin piston positive displacement pump since surface geography and infrastructure prevented the plant from being placed directly above the orebody.

Figure 7 Lady Loretta paste plant

3.3 Mine 4

The Mine 4 plant is almost certainly one of the most unique paste plants in the world. Whilst wet tailings was available at this site, due to a series of reasons the mine selected a reclaimed tailings system from an operational TSF. Previous experience at other sites indicated reclaiming material from an operating TSF was extremely difficult and the material tended to be very wet. As a result, the paste system was designed to treat very high moisture content material. The strategy was that if the tailings could be discharged from a loader bucket, it could be treated by the paste plant.

As a result, the plant shown in Figure 8 was designed and constructed to produce 150 m^3/h. This plant operated for a number of years with paste filling now stopped at the mine. At this plant the tailings is discharged over a large grid directly into a twin shaft Sicoma batch mixer. Within the mixer, water was added slowly to produce an uncemented paste. Initially this plant was to be located within the open pit above the underground orebody. In fact, all the plant fabrication had been completed by the time the paste location was changed due to large scale cutback of the open pit. As a result, the plant was constructed on a mine waste dump as this was the only location available.

From the tailings mixing plant the uncemented paste was pumped via a dual piston positive displacement pump to the pit edge. Adjacent to the pit edge was a 500 t binder silo and cement slurry mixing facility using a colloidal mixer. The cement slurry was produced and metered continuously into the main paste pipeline at the top of the pit.

The cement slurry and tailings paste subsequently mixed in the pipeline that extended down a series of boreholes and horizontal sections.

Figure 8 Mine 4 paste plant

Overall the plant was a moderate success. Due to the plant location and high mine personnel turnover the construction phase became quite extended. Once in operation the tailings reclaim process was quite costly due to the heavy interactions with the tailings disposal facilities. The tailings were also extremely wet at times and would bridge over the grid above the mixer.

The greatest learning on this plant was also very simple. If the water addition to the batch mixer was completed too quickly the resulting paste tended to be quite 'lumpy' and would cause blockages of the pump. Once this was changed to a slower addition allowing the material to change state more slowly, a significantly improved product was produced with no blockages of the pump inlet.

Whilst there was an ongoing maintenance requirement on the pump, the remainder of plant proved to be robust, with low maintenance requirements. The cement slurry plant operated adequately, although the cleaning requirement was relatively high as the colloidal mixer was modified to generate significantly higher volumes of slurry. Overall the cement slurry and tailings paste tended to mix well in the pipeline from the intensive mixing within the freefall and impact zones.

As with all the other designs in this paper, the ability to produce and place good quality, high solids content paste was particularly successful. Figure 9 shows a collection of laboratory prepared paste samples of the tailings used for paste production at different times. The graph highlights that due to changing tailings properties, the solids content to achieve a 200 mm slump changes dramatically over time and also the significant strength improvement generated by increasing the paste solids content. The graph also shows that a unique relationship of strength versus solids content may be used for these different tailings properties.

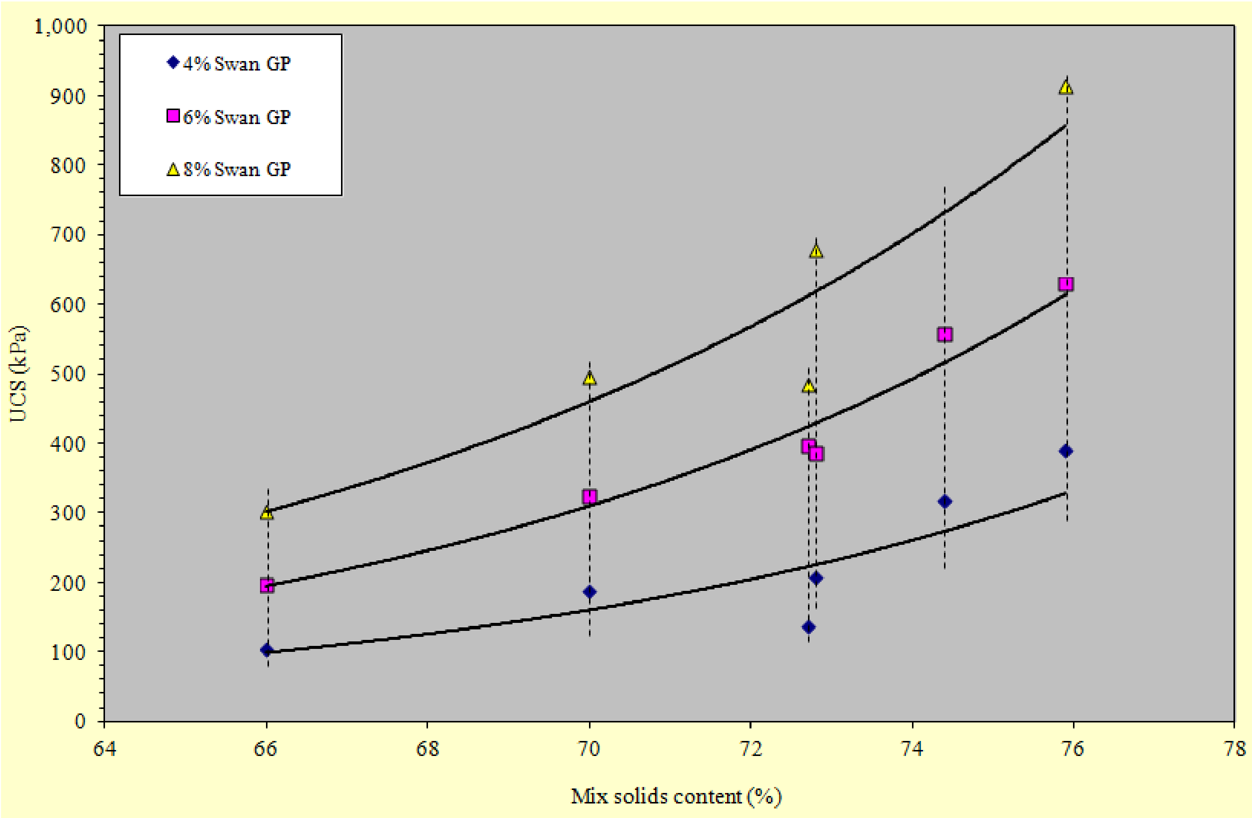

Figure 9 UCS and mix solids content relationship at Mine 4

It is considered this style of plant has significant potential to treat very high moisture content tailings in the future and building upon the learnings, it is certain future plants will have significantly less commissioning challenges.

3.4 Peabody Wambo

Wambo has presented the largest backfill challenge of all the projects presented in this paper. Wambo is a coal mine and backfilling of near surface historic room and pillar areas was required to prevent excessive surface subsidence prior to a longwall extending beneath the old mining areas. A total of 250,000 m^3 of fill is required with 70,000 m^3 placed at the time of writing this paper.

To fill the old workings, over 100 boreholes were drilled on a grid pattern over an area of 800 × 800 m. What has made this job so difficult is the feed material which is surface alluvial material consisting of a high quantity of moist surface clays, a portion of abrasive sand and a high quantity of extremely hard 'river rocks' with significant variability thrown in.

Due to the challenges associated with material type and variability, the option of using a stationary plant and pumping was eliminated as the risk of constant pipe blockage was considered too great. As a result, a completely mobile solution was developed. As shown in Figure 10, the plant consisted of two separate trailers. The material feeding section uses a similar design to Spotted Quoll and the second trailer contained 50 t of binder storage and an on-board generator for full power generation.

The intent was that the plant would move every two to three days, with both trailers fully coupled. Due to poor road conditions, especially after rainfall events, the trailers are decoupled prior to each move.

Figure 10 Mobile plant on the move

The time spent filling each hole varies from one to 10 days, depending on the location and mine workings. When the filling campaign is only short, the plant is fed via a MISU bucket and excavator as shown below in Figure 11. When the filling volume is greater, a mobile ramp is used with screening first completed by an excavator and the plant fed with a wheeled loader.

Figure 11 Mobile plant in production

As described, the challenging material has caused a range of issues on production and whilst some process improvements have been implemented, the challenges are still significant.

As with Spotted Quoll the strength of the MISU bucket is its ability to handle very moist material and break up cohesive lumps of soft material. However, the MISU can also tend to force through larger elongated rocks. This characteristic along with extreme wear rates has often resulted in significant rocks being captured and blocking the screen above the paste hopper as shown in Figure 12. This screen can become completely blinded within 10 minutes. Due to the high clay content the paste also tends to be quite sticky which further restricts flow through the protective screen above the hopper and borehole even when rocks (see Figure 12) are not present, which significantly reduces the throughput of the plant. As the boreholes on this job are only a little larger than 100 mm the screen aperture cannot be too large due to risk of blocking the boreholes.

To limit the risk of blockage due to oversize rocks, a trial incorporating a traditional mobile vibrating screen is planned in December 2013. Whilst this will most certainly improve the feed product to the backfill plant, there is significant risk, especially in times of high rainfall, that the material will be too wet to be processed through a vibrating screen. Steps are also being put in place to avoid selection of feed material with high clay contents.

The second major issue encountered is the highly abrasive nature of the product and the rocks. Significant wear on all mobile equipment, plant conveyor belts and the mixer have occurred. The clay content results in material building up in some areas. The sand and rocks then contained within the clay medium act as very abrasive media, wearing through belts and mixer paddles and seals. This clay natured build-up also results in a high requirement for mixer cleaning even though the binder contents are relatively low.

As outlined for Spotted Quoll there is significant opportunity for mixer improvements. The Wambo mixer is now considered a test bed for a range of improvements aimed at addressing the challenging material. The challenge of improving material flow through the screen above the paste hopper and borehole also continues with an eye on ensuring improvements does not generate excessive risk of borehole blockages.

Figure 12 Build-up of clay and rocks on screen

4 Tritton wet tailings paste system

A single wet tailings paste system is presented at Tritton. The Tritton paste process consists of thickener underflow fed to a 400 m^3 agitated storage tank with full generator power backup. The tailings slurry is fed to a single 131 m^2 belt filter that dewaters the slurry from 60-77% solids by weight. The filter cake discharges onto an inclined belt. This plant also includes a material hopper and belt feeder. This allows crushed mine waste to be added to the paste. This option was included as the mine licence requires the mine waste to be returned underground. Only limited volumes of mine waste have been added to date. The filter cake from the inclined conveyor enters a twin shaft continuous mixer. Tailings slurry is added via a variable speed pump to the mixer to control the paste solids content and rheology.

The binder system is very similar to Newmont Tanami with a Schenck mass flow meter used. It is interesting to note that at this site there were no issues at all using a screw auger to feed the unit. This highlights the variable nature of different binders and that a proven design may not be directly transferrable for another application or site.

The mixed paste is discharged over a 50 mm aperture vibrating screen via a level controlled paste hopper to underground.

Figure 13 Tritton wet tailings paste plant

As described earlier, historically disc filters have been used in the majority of paste plants. Whilst disc filters are simplistic and constant improvements are being made to their design they are generally a maintenance intensive piece of equipment due to the regular filter cloth changes. Historically belt filters were considered too high a cost and their footprint too large for the majority of paste applications. However, as the cost of belt filters continues to decrease they are becoming a real alternate option to disc filters. Belt filters are already widely used in other mining applications.

The main advantage of belt filters are they require significantly less operational maintenance with the filter cloth lasting for 12 months. They also have no moving parts within the slurry. The key disadvantage of a belt filter is they are a more complex piece of equipment and as a result trouble shooting and repairs are more difficult.

Figure 14 Filter cake being produced at Tritton

Since commissioning in early 2011 the plant has operated well with only minor maintenance and operating issues, although there have been two significant underground reticulation blockages. Other than general maintenance the major issue experienced is the effect of wind on the filter cloth when the system is not operational. A cover for the filter was excluded due to cost constraints so when not operating spring clamps are placed on the filter cloth to prevent the wind picking it up and destroying the cloth.

A key aspect of the plant is the ability to constantly produce high quality paste. A detailed review of the operation was completed in January 2012. For a given curing condition and duration, the strength of paste fill is most significantly influenced by binder content and dry density. The final dry density of paste is dictated by the paste mix solids content and for a given tailings material the aspect that limits the solids content is transportation of paste.

Therefore, in an effort to minimise binder content (accounting for 60% of the fill operating costs) at Tritton, it is most appropriate to target the highest possible solids content and set the binder to the attainable solids content and the strength requirements.

The review in January 2012 conducted by Outotec concluded “It is noted that the measured friction loss is generally very close to the limit as determined by the flow model, which is an indication that the operators are striving to achieve the highest quality (solids content) paste.”

5 Conclusions

This paper has presented a series of paste plant designs implemented in Australia in the past five years. The design basis and golden rules were presented and the encountered challenges highlighted. Paste plant designs continue to advance, suiting variable materials, whilst the cost of construction is optimised, with costs becoming even more crucial in the commodity downturn. The critical factor is that the plant designs take a holistic approach and that paste systems take both capital and operating expenditure into account to produce the most efficient, targeted, life-of-mine solution. In most cases this means ensuring the plant can produce high solids content paste as this generates the potential to obtain significant binder cost savings over the mine life.

Acknowledgement

The author would like to acknowledge Glencore Lady Loretta Mine, Newmont Tanami, Western Areas Spotted Quoll, Peabody Wambo and Tritton Copper Mines for their support during the design, construction and operation of the mine backfill facilities.