Tailings Thickener Improvements at Sentinel Copper Mine

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Great advances have been made in thickening technology over the last 40 years with the development of high-rate thickeners and the application of high molecular weight synthetic flocculants. These developments have enabled high throughputs to be fed through individual units, saving both space and capital. Like all great progress, this comes at a price and modern high-rate thickeners can be more difficult to operate than large conventional-type thickeners. This leads to a situation where many thickeners are running under conditions far from the optimum, meaning high flocculant consumption, limited capacity, poor underflow density and high solids in the overflow. At Sentinel Mine, the tailings thickeners were suffering from all of the above and even very high flocculant dosages failed to control the situation. Kemira and the plant's staff working together successfully tackled the underlying issues, bringing the performance back to and then above expected levels

INTRODUCTION

On a high level, successful flocculation depends on three main factors:

1. Having the correct flocculant;
2. Adding the correct amount of the flocculant;
3. Adding this amount under the correct conditions.

Although superficially very simple, in practice few plants run thickeners and counter-current decantation (CCD) trains without difficulties. The paper is intended assist in this area by highlighting the approach that was successfully used at the Sentinel Mine.

The starting point is to understand the basic principles behind high-rate thickening. This then determines the conditions necessary within the thickeners and especially within the feedwells. Although these principles are well known in the industry, the knowledge and the application of this knowledge to the plant is often lacking. In the case at the Sentinel Mine, with a new plant, different equipment and a largely new workforce, it created a challenge. This paper highlights some of the areas worked on and the tools used. It is not intended to be a "how to" guide but to illustrate where, using the fundamental principles, potential improvements can be made. It also highlights how laboratory-scale experimentation can be a valuable tool to understand and communicate these principles.

BACKGROUND

The Sentinel Mine is a new large-scale copper flotation operation situated in the western extension of the Zambian Copperbelt. Currently it is the largest copper mine in Africa in terms of throughput and in 2017 processed 42M tons of low-grade chalcopyrite ore. The circuit is relatively straightforward with semi-autogenous (SAG)/ball mills followed by roughing and cleaning flotation stages. Concentrate is filtered and shipped to the local smelters, tailings are thickened and then pumped more than 10 km to the tailings storage facility (TSF).

The tailings treatment plant consists of 3 × 50 m diameter high-rate thickeners fed from a central distribution launder. Overflow discharges by gravity into a large process water tank. The tailings are taken off to the holding tanks and then pumped out along the two tailings lines to the dam.

THE CHALLENGE

The plant started commissioning during 2014, with the initial focus concentrating on obtaining the required grade and recovery from the flotation circuit. In 2015, a positive water balance in the TSF led to a review of the tailings operation and associated parameters, including the tailings thickener underflow density. Findings concluded that a lower-than-expected underflow density meant that excess water was reporting into the dam and action was needed. At this stage, operating the thickeners was difficult, with flocculant dosages of more than 30 g/t being considered normal and, despite the high dosage, there was regular sliming with the mud bed overflowing. The underflow density was low at around 40% solids. The design specifications were for a flocculant dosage of 12 g/t and an underflow density of 55%.

An initiative to improve thickener operations was started in 2015 and Kemira was invited to assist on site. Issues requiring attention were identified in several areas, especially with the performance of the thickener feedwells. The main problem was that the flow of dilution water into the feedwells, via the dilution channels, was erratic, leading to high solids levels in the feedwells and slow settling. This was further compounded by having the flocculant addition into the channels. This design meant that if the channels stopped working, a majority of the flocculant dosage flowed into the body of the thickener and never reached the feedwell. This dilution flow often stopped when the bed level was high, leading to the situation of very poor flocculation at the most critical times. Recovering the thickeners from upsets without the correct dilution was difficult and slow.

The approach taken by the process personal together with Kemira first involved developing a basic understanding of the flocculation behaviour, then identifying the preferred conditions for the flocculation and finally modifying the plant to utilise these conditions as far as practical. The work required both physical and operational changes and progressed steadily through 2016 and 2017. The plant is now performing well with low flocculant dosages and high underflow densities. Efforts continue with the objective of minimising dosage/cost and improving the underflow density further.

SOLUTION

The challenge was tackled using a more holistic approach to the flocculation rather than simply looking at products and substituting one flocculant for another. This approach used a strong emphasis on developing understanding of the flocculation and how the design, set-up and operational aspects influence this. Work was carried out in several areas including:

- feedwell design and operation;
- flocculant dosing configuration (dilution and distribution);
- flocculant make-down system;
- product selection;

- operator awareness/understanding and troubleshooting skills;
- thickener control and on-going improvements.

Feedwells
From a flocculation perspective, the feedwell is the most critical component of any high-rate thickener. At Sentinel, these were a vane-type design fitted with a tangential feed entry and three dilution channels. Analysis of their behaviour was visual. with time being spent on top of the thickeners, watching over different conditions. Emphasis was placed on understanding the flow patterns within the feedwell and on the performance of the dilution channels in particular (Figure 1).

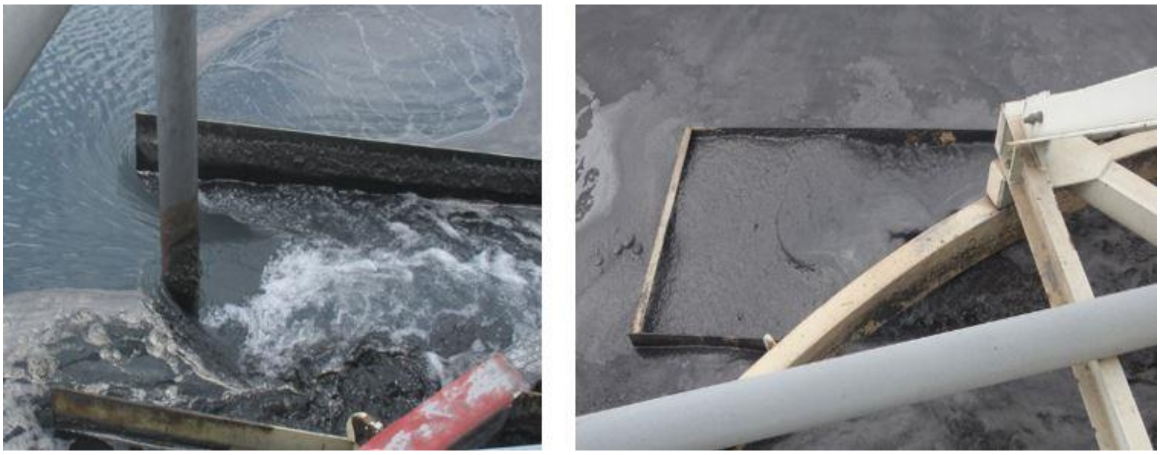

Figure 1: Feedwell dilution channels operating well and poorly.

The dilution of the pulp to achieve faster settling is the key principle in high-rate thickening. If the dilution is not present then a high-rate thickener is effectively converted to a conventional-type thickener, settling rates are considerably slowed and the usual result is sliming. At Sentinel, it was seen that, under certain conditions, the dilution flow through the channels could be slowed or even stopped. Without a strong flow in the channel, the coarse material quickly sanded-out, thereby blocking the channels and stopping the dilution flow until they were physically cleaned (Figure 2). To compound the situation further, two of the three feedwell flocculant addition points were into the channels: without an inward flow the flocculant bypassed the feedwell and was lost into the body of the thickener. Although there were valves fitted onto the flocculant lines to help to prevent this, the operators rarely used these.

Figure 2: Sanding-out in channel.

When operating, a cycle was created whereby a high bed level slowed the dilutions flow in the channels. This then increased the solids levels and at the same time cut most of the flocculant dose into the feedwell. Both factors together slowed settling considerably, making the bed rise further. High flocculant dosages (>60 g/t flocculant with the dosing pumps running at 100%) had no effect under these conditions: recovery often required a reduction in the feed rate.

Laboratory testwork quickly identified the sensitivity of the settling rate to changes in feedwell solids levels (Figure 3).

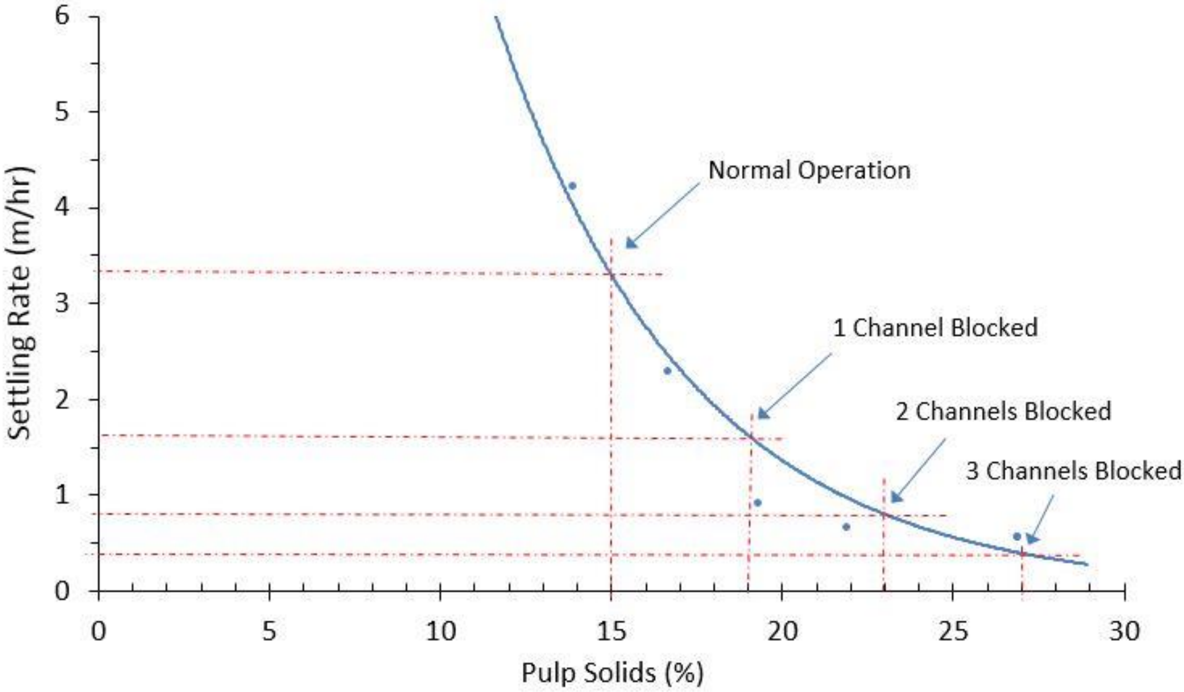

Figure 3: Effect of pulp solids on flocculation rates.

Making the assumption that the three channels provide about equal dilution and that the target in the feedwell is around 15% solids, we can see that:

- With one channel blocked, the solids increase to 19% and settling rate halves;
- With two channels blocked, the solids rise to 23% and the settling halves again;
- With all three channels blocked, solids are around 27% and the settling rates are less than 0.5 m/h.

Corrective action was to install high-pressure flushing lines, carefully positioned to de-sand the channels quickly and easily. If necessary, these could also be left running to pull in more flow as well as contributing to diluting the pulp themselves. The original configuration was vertically into the channels but this was later moved outside of the channels and fed into the mouth with a fishtail outlet (Figure 4).

Although this flushing was highly effective, it was found that there was insufficient high-pressure water to run all of the lines continuously and their use needed to be carefully judged. Inspections when the thickeners were emptied showed that the sanding out has now largely disappeared. Work is now ongoing with a modification to connect the unused underflow recirculation pump to take overflow from the surface of the thickener. This will then feed a dedicated flush/dilution circuit running independently and continuously for each thickener.

The original configuration had baffles installed shortly after the slurry inlet to improve mixing at the low flowrates expected during the commissioning and ramp-up phases. These have now been removed and there is considerably less turbulence in the feedwell (Figure 5). The flow pattern in the feedwell is more centrifugal and stronger and this helps to pull in more dilution from the channels.

Figure 4: Flush line detail.

Figure 5: Mixing baffles and their removal.

In conjunction with the above modification, the mixing baffles in the dilution channels have also been removed, which further increased the dilution flow in the channels (Figure 6).

Significant changes were made to improve the feedwell geometry, with baffles and guide plates all being extended upwards and some also lengthened (Figure 7). This modification helped to prevent slurry entering the channels and contributing to the sanding-out process.

Other improvements, designed to make cleaning the thickeners easier, included extending the walkways across the whole diameter and installing a drain valve below the underflow outlets to allow the thickener to be emptied more completely.

Distribution cones from the undersides of the feedwells were removed from two of the three thickeners. This appears to have helped to improve the dilution flow in the channels and so far there have not been negative effects on the underflows or the rakes.

Figure 6: Channel mixing baffles.

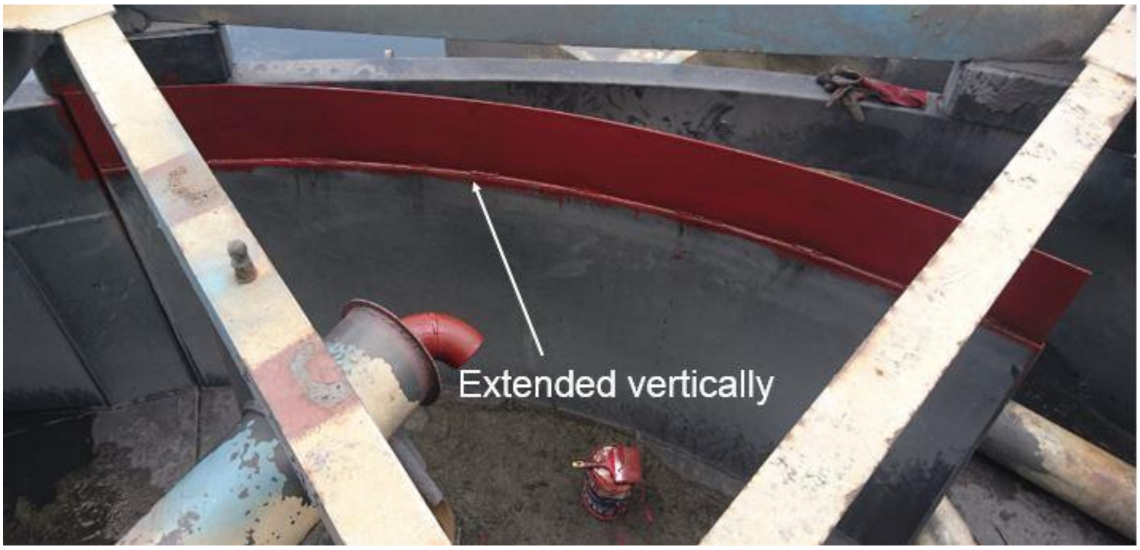

Figure 7: Baffle modifications.

Flocculant Dosing and Distribution

To improve the mixing in the feedwells, considerable effort was focused on the secondary dilution and flocculant's distribution circuit. The original configuration was built with a split dosage and had been operated with 50% of the dosage going to the feedlines and 50% to the feedwell. This split was questioned and slowly the bias was changed towards the feedwells, eventually stopping the feedline addition altogether. This freed up a standby dosing pump. At Sentinel, good overflow clarities could be achieved without the split and it was thought to be mainly wasting flocculant.

The flow of the feedwell flocculant dilution stream was increased and the floc dilution boxes were extended upwards (Figure 8) to allow for this higher flow without overflowing.

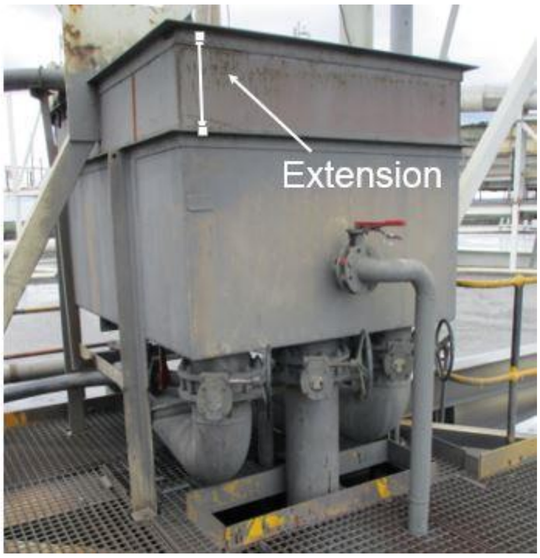

Figure 8:. Increased volume in dilution boxes.

Flocculant distribution points in the feedwells were changed from three single points (two on the channels and one point within the feedwell) to six points with a more dispersed outlet system. The configuration currently in use has two dosing points into the channels via distribution plates and a further four points onto and into the feedwell itself. The additions into the channel have been moved closer into the feedwell and angled to give inward momentum. Now if the channel flow slows or stops, the flocculant will generally come into the feedwell, rather than be wasted. Some flocculant is currently added on the surface but this is slowly being changed, to add it under the surface and more directly into the slurry stream using smaller diameter "fingers" run out of the larger diameter pipework (Figure 9). Residual flocculant is consistently low and typically less than 0.2 mg/L.

Figure 9: Improvements to flocculant distribution.

Make-Down and Dosing

There were several problems with the make-down equipment, the most significant of which was the formation of lumps inside of the hopper. This lead to a lot of stoppages to clear blockages as well as inconsistent solution strength. The inconsistent solution strength contributed to the operators running with a high flocculant dosage to compensate for occasional weak batches being transferred. The cause of these lumps was the ingress of damp air into the storage hopper, forming lumps on the side walls when in contact with the powder. These lumps then fell off causing the blockages in both the screw feeder and the venture.

Figure 10: Hopper opening changes detail.

Corrective action was to seal hopper itself and a new lid and with a smaller opening was fabricated locally (Figure 10). The filling procedure was improved and limited to once per day. The building itself was made more watertight, with doors being fitted and a canopy installed to keep rain out of the lower working area (Figure 11).

Figure 11: Flocculant building modifications.

The configuration has now run through two rainy seasons with minimal blockages. One very positive benefit of this was to improve the housekeeping around the make-down unit: it is now possible to keep the floor clean and has eliminated a major slip hazard.

Further problems were caused by the tripping of an undersized agitator in the make-down tank. This limited the viscosity of the solution that could be handled and the concentration had to be reduced. This was, in fact, beneficial as it forced the operators to run with a lower dosage, regardless of how fast they set the dosing pumps. Despite changing the agitator, the low concentration has been kept and the system is now running with flocculant at a 0.15% solution strength.

Magnetic-type flowmeters were fitted to the flocculant lines. Control of the flow has moved from pump speed to the flowrate in m^3/h via control loops in the control system. This gives great confidence that the required flow is actually being delivered and we would strongly advise that these be fitted to all dosing lines.

Product Selection

The initial product selection was carried out in Australia and led to the choice of a low-charge anionic-type flocculant; however, once the plant was running, the water chemistry was different and the anionic charge demand moved upwards. The screening in September 2015 (Figure 12) showed a clear preference for the higher anionic charge types.

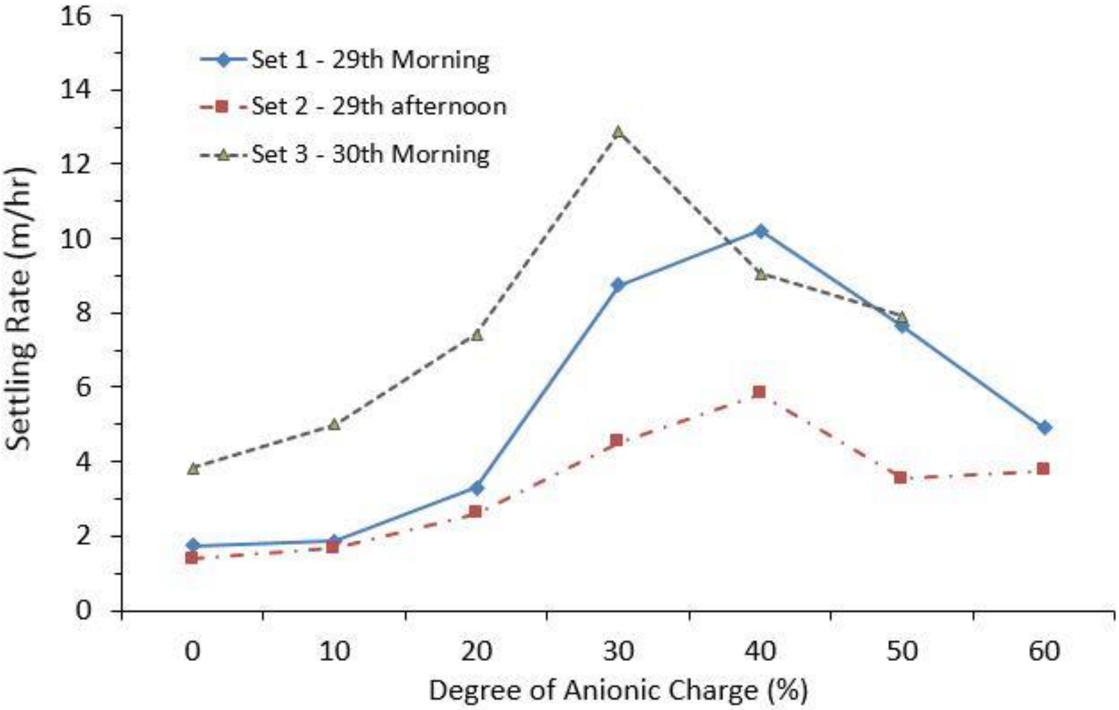

Figure 12: September 2015 basic product screening.

To give further confidence in the testwork, several sets were carried out using pulp taken on different days and flocculated under different conditions. Further work undertaken since 2015 has continued to confirm this trend and it forms an important part of the ongoing support. This case highlights the need for caution in starting up operations and that the assumptions made in reagent selection may need to be changed. With flocculation, the chemistry of process water is a more important factor than the mineralogy of the solids.

Operator Awareness

Awareness was raised with a training program being rolled out across the supervisor and operator teams. This training program concentrated on understanding the design principles for high-rate thickeners and basic troubleshooting. Considerable emphasis was placed on the feedwell dilution channels and their correct operation and what to do when the dilution flows were seen to be dropping.

The reasoning for keeping the flocculant dosages as low as possible was also stressed, particularly the negative effects that a high dosage can have on underflow density. Alternative strategies for coping with problems were developed to break the operator's normal habit of immediately increasing the flocculant dosage in the event of any problem. The training used both slides but, more importantly and designed to be most memorable, were a series of bench-scale demonstrations to highlight the principles of dilution and mixing in high-rate thickening.

Thickener Control

During the start-up and initial operation, with the focus on the flotation circuit, few changes were made to the control system.

Problems with the flocculant make-down equipment blocking meant that there was little trust in the flocculant's solution strength. To manage this, each batch of solution was measured for strength and this assay added into the control system to be factored into the dosage calculations. Although this sounds good in practice, actually measuring such a low concentration using a hand-held density meter was difficult and results were inaccurate. In effect, the assay process was introducing more variation into the flocculant dosage control than was actually present.

The solution was to leave the concentration in the control system fixed and the assay became simply a check against very dilute batches getting through. Load cells have now been fitted onto the flocculant hopper and act as a further check that the correct mass of flocculant has been added to each batch. An improved refractometer, capable of working to six decimal places, is now being used for measuring the flocculant concentration.

Initial control of the flocculant dosing was on a manual basis, with the dosing pump speed being set on the control system. This arrangement had several disadvantages, mainly in that as the feed changed the flocculant dosage did not. Consequently for most of the time we were either overdosing or underdosing. This was modified to a system based on a dosage set in g/t with the control system automatically scaling the dosage to the feed. As well as the scaling, the main advantage of the dosage being controlled in g/t is that it gives visibility to everyone involved with the process. It is immediately apparent if the dosage is high or low. With the dosage set in L/h, there is little idea of the real dosage unless complex calculations are done. The actual g/t settling to be used is now decided on with the thickener operator and control room operator working together. If the bed starts rising or the overflow looks particularly turbid, the dosage is increased. Reducing the dosage is still proving difficult.

Bed level measurement remains an issue, with the ultrasonic bed level probes that were fitted being only partially successful. With a clean interface between the mud bed and supernatant they work well; with solids in the path, they cannot give an accurate reading. Manual sampling tubes are used to measure the bed level, with one being kept on each thickener bridge. For the overflow, simple clarity wedges are used and the lighting improved with bright clear light-emitting diode (LED) types installed to assist with night-time operations.

The original configuration had an underflow recirculation pump fitted to each thickener to keep the mud moving during periods when the thickener feed was stopped. In operation, this caused major problems when recirculating, with the underflow density continuing to build, leading to several incidents of the rakes stopping. Operating procedures have been changed and now, when stopping a thickener, the underflow pump is continued to run until a large part of the solids has been removed.

The control systems' original design had a minimum volumetric flowrate of 3500 m^3/h in the tailings lines to ensure a minimum velocity to prevent sanding out. This minimum velocity forced the underflow pumps to ramp-up, thereby reducing the residence time in the thickeners and compromising the density achieved. By reducing the minimum velocity in the tails line, the underflow pumps automatically slowed down, thereby improving the underflow density. This was especially important when operating with reduced feedrates.

As a further improvement, work has started on adding a dilution line to each tailings line so that, at low treatment rates, extra water can be added to increase the tailings line velocities and help to prevent the sanding-out. This will let the thickener underflow pumps be controlled to maximise density rather than be governed by the need to pump a minimum flow.

RESULTS TO DATE

The plant is now running well with the flocculant dosages between 10–15 g/t and able to cope with very high feedrates.

Improvements to the underflow density have been highly successful (Figure 14) and the underflows have often exceeded the 55% target for long periods.

Figure 14: Monthly Underflow density trends 2016–2018 (SCADA data).

Sliming incidents are now unusual and are the exception, rather than part of everyday operation.

Overflow clarity is generally good and runs clean most of the time (Figure 13). With one flotation train, operating the dosages can be reduced to around 6–8 g/t.

Quantifying the effects of each individual change has been difficult: looking for a 1 or 2 percent improvement against the normal variation in the process is not possible with any degree of certainty; however, on an overall scale, the change to the plant's performance has been very significant.

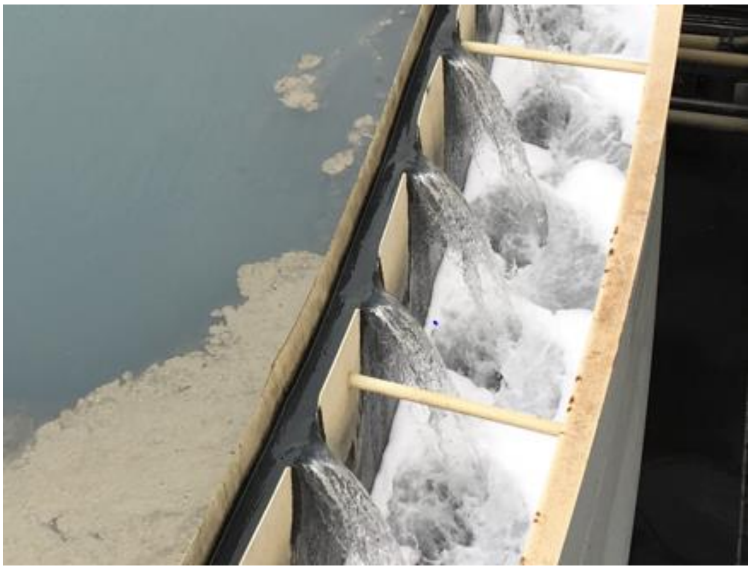

Figure 13: Typical overflow clarity on Thickener No. 1.

CHALLENGES REMAINING

The biggest issue is still operator awareness and further training is planned in this area. With the dosage remaining under the operators control, there is still a tendency to overdose or, more correctly, not to reduce the dosage when conditions are good. Successful automation of the dosage is the target but this will require additional instrumentation to give the necessary inputs.

With the changes to the tailing lines, the constraints to underflow pumping will shortly be removed and the target will be to operate the underflow pumps to maximise density rather than to the minimum flows needed for the tailings lines. This, along with improvements to the control loops, should enable the underflow density to be improved further and consistently closer to 60% solids.

The dilution channels can still be problematic under certain conditions and work to implement the permanently running dilution/flush lines is underway and should help.

As with most operations, there also remains the challenge of coping with the varying ore types from the pits and keeping throughputs to match Sentinel's production targets. Better flocculation conditions will help with both.

The work has been more difficult than simply changing from one flocculant to another and has taken considerable effort on the part of a lot of people from the Sentinel Mine to implement these changes. The results so far have been very good and, using the principles developed, there is great confidence in achieving the further improvements targeted.