DEBOTTLENECKING OF THICKENERS IN A CHANGING ENVIRONMENT

Abstract
Thickeners are utilized in mineral processing for the purpose of solid-liquid separation (dewatering). Thickeners separate an incoming feed slurry (i.e. water with solid particles of either product or tailings material) into two distinct streams; one consisting of clarified water and the second stream being a slurry concentrated with solids.

Thickeners, like most processing technology utilized in minerals processing, are fixed geometry equipment designed for a specific throughput and duty. During the course of the thickeners’ life cycle, in excess of 20 years, they are commonly called on to perform to new process requirements due to changing mineralogical circumstances, revised plant performance criteria and external changes in the operating environment. In addition, aging equipment requires increased levels of maintenance to prevent unplanned shutdown from occurring.

To meet these changing conditions, the operator has an option to upgrade, or modernize, the thickener to ensure it continues to provide the required outcomes efficiently and sustainably. This white paper will discuss the modernization options available for thickeners.

After a brief introduction to the thickening process we move on to discuss the global external pressures on mine operators to give context to the discussion and elucidate the need for efficient resource use.

Next, we look more specifically at how these external influences impact the operator, then we briefly review the options available to overcome these challenges, and we discuss the owner’s decision process: “Modernize or buy new equipment?”
In assessing the decision to modernize, we consider the elements of an upgrade and the advances in thickening technology that allow operators to meet new challenges.

Finally, we will discuss the process of modernizing a thickener so as to achieve the client’s stated outcomes. This includes identifying the issues, working through an investigation process, testwork, and engineering prior to the delivery and implementation of the modernization.

**Key words**

Thickener, modernization, dewatering, upgrade, tailings thickening, concentrate thickening, feedwell
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1 Overview of the Thickening Process

Thickening technology utilizes the principle of sedimentation as a cost effective method of solid-liquid separation.

Sedimentation is used to thicken an incoming feed stream to produce two phases:

- Overflow - a stream containing minimal solids
- Underflow - a stream containing minimal liquid

This is accomplished by a number of means inside the thickener:

- Settling under the force of gravity
- Addition of reagents such as flocculants, which are mixed with the incoming feed to enhance gravity settling such that it occurs faster or at a higher rate
- Bed compression due to self-weight of material in the settled bed
- Mechanical raking to release water trapped in the settled bed

Compared to alternative technologies, sedimentation using thickeners is capable of processing high volumes of slurry at a relatively low cost.

During operation the two outputs, overflow and underflow, are rarely prioritized simultaneously. The duty of the thickener will determine which of the two is prioritized.

In tailings applications where recovery of water and minimal-sized tailings storage facilities are desired, underflow will be targeted to the detriment of overflow performance.

Conversely in a typical concentrate application, overflow clarity is an important requirement: otherwise the valuable mineral would be returned to the concentrator with loss of recovery and additional process costs in the form of reagents and maintenance.

Further considerations in thickener performance targets are determined by downstream equipment and processes, and upstream where the returned water enters the process.

Critical to thickener performance are two parameters:

1. Solids loading based on dry tonnes of solid entering the feedwell
2. Rise rate based on the flow rate (cubic meters per hour) entering the thickener including dilution water

Both solids loading and rise rate are expressed as unit rates [tph or m³/hr] per square meter of thickener surface area. For existing thickeners, these two parameters are effectively predetermined as the available surface area depends on the thickener’s diameter.

Hence, while better control and operation is able to improve the average performance of an existing thickener, the ultimate performance is limited by the ability of the feed system to promote faster settling of the material and so allow for more aggressive ‘sizing parameters’ – solids loading and rise rate.

Consequently, improvements in thickener process performance typically include efforts directed at improving the feed system, from upstream of the thickener through to the feedwell. How far upstream this takes place will depend on the plant itself, taking into account the effect of feed properties, combined streams and elevation changes. Any components not optimized will affect the efficiency of the settling in the thickener and therefore its capacity and performance.

2 External Influences

Business owners globally are facing macro forces that affect their planning and daily operations and mine owners are not immune to these trends. These external challenges impose upon mine operators a new paradigm to ensure they meet society’s requirements to not only provide the raw materials for global growth, but also the increasing demands to do so in an environmentally and socially sensitive manner.

Thickeners in an operating mineral processing plant play a vital part in the context of these external influences, assisting operators to meet growing demand efficiently and sustainably while offering investors a suitable return. As a key piece of equipment in the dewatering phase, the impact of thickener performance on overall plant operations should not be understated.

2.1 Demand Growth

Driven by demand for more minerals in recent years, capacity expansion plans have consistently featured in the strategies of mine owners. Even in a climate of declining demand and prices, expansion plans are still under consideration, whether to position for future

![Figure 1. Mines at expansion development stage per mineral type (SNL Metals & Mining 2015).](image-url)
growth or maintain capital efficiency and thereby reduce unit production costs. An analysis of expansion projects presented in Figure 1 provides some context for the importance of plans to expand operations, even at a time of low metal prices and uncertainty. The analysis data lists over 280 plants with expansion plans across all mineral types. (SNL Metals & Mining 2015.)

The benefit of expanding existing plants over greenfield development is clear. As ore body knowledge increases over the operating life, technical risk is reduced and the capital efficiency of the existing plant is increased as it is extended beyond its original life or capacity.

2.2 Water Scarcity and Social Impacts

From an environmental and social perspective, efficient thickener performance is becoming increasingly important. Operating licenses are progressively more onerous, requiring strengthened assessment and mitigation of the likely impact on the local environment and communities. In particular, access to water is more tightly regulated due to increasing awareness of scarcity, motivating operators to look for new and sustainable sources of water.

In a news release from July 2013, BHP Billiton announced a joint investment in a desalination plant for the Escondida Mine in Chile, of which it owns 57.5%. BHP Billiton will invest USD 1.972 billion for a total investment of over USD 3 billion by all of the partners involved. The investment simultaneously demonstrates the importance of water to mining operations, and the huge cost associated with overcoming water scarcity.

Mining activity produces more than 10 billion tonnes of tailings every year (CRC Care 2013). At between 30% and 55% solids by weight this can equate up to 7,000 gigaliters of water discharged to tailings. Even a 1% or 2% increase in thickening efficiency can lead to savings to mining operations of up to 1,400 gigaliters of water per annum. Figure 2 shows the volume in comparison to a large city consumption. In 2014/2015, Melbourne in Australia, a city with a population of over 4.4 million people, consumed a total of 401 gigaliters of water. (Melbourne Water, 2014).

Societal awareness of mining activities is also driving decisions by owners and operators. In an SEC filing from February 17, 2016 Newmont Mining reported in relation to the Conga Project that it “will not proceed with the full development of Conga without social acceptance, solid project economics and potentially another partner to help defray costs and risk; it is currently difficult to predict when or whether such events may occur.” The filing further reported “Under the current social and political environment, the Company does not anticipate being able to develop Conga for the foreseeable future.” The processes of obtaining and maintaining a social license to operate are playing an increasingly important role in decision-making among mine operators worldwide.

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**Figure 2.** Water in tailings and saving potential in comparison to a large city consumption (CRC Care 2013; Melbourne Water 2014).
3 Thickener Challenges

The demand for minerals to sustain the growth of urbanization and the movement of millions of people to middle-class lifestyles has a consequential impact on operators, who must ensure efficient resource utilization, both in terms of capital and natural resource usage.

3.1 Lower Grades and Changing Ore

As higher grade materials are depleted in early years of operations to meet Return on Investment (ROI) targets, plant expansion to meet the growing demand has seen the exploitation of lower head grades within existing mining tenements. This provides a faster path to market to take advantage of higher prices as well as being capital efficient.

According to research by Wood McKenzie (2015), copper grades have fallen over 35% since 1990 and the long term-trend does not see any improvement [Figure 3].

The declining grade increases the momentum for planning plant expansions as owners need to increase plant throughput to maintain mineral output at economical levels.

A further consequence of this move to lower-grade ores is a general reduction in average particle size, with further effects on the thickening properties of slurries. Furthermore, changes in ore mineralogy occur as new satellite bodies are accessed to feed plant expansion to meet new demand.

These process circumstances, increased throughput due to lower grades and changing mineralogy and particle size, have a direct impact on thickener performance. Increasing the solids load on a thickener will necessarily result in a decrease in thickening performance in the absence of any modernization improvements.

![Figure 3. Grade trends weighted on payable copper - including probable projects (Wood Mackenzie 2015).](image-url)
Figure 4. Changing throughput impact on performance and typical outcome of increasing the solids loading (SL) and changing the ore to an existing thickener.

Figure 4, representing a typical copper tailings thickener, shows that increasing the throughput of a thickener of fixed diameter (by increasing solids loading) reduces underflow density and consequently increases the amount of water sent to tailings.

Similarly, changing ore characteristics, such as particle size distribution (PSD), can also negatively affect the underflow density and water sent to tailings as shown in Figure 5.

Even for greenfield plants, there are cases when the actual conditions will have changed from those used in design when many assumptions will have been made based on limited knowledge from small sample sizes of drill results. If changes are significant modernization of components may be required to deliver performance.
3.2 Aging Equipment

Beyond the process-based sedimentation challenges facing operators, extending the capacity and life of existing equipment also requires a focus on the mechanical components of a thickener. The capital-intensive nature of minerals processing plants motivates owners to pursue capital efficiency, measured by throughput and operating availability. Modernizations are an ideal route to achieve this outcome.

Recently there has been a sharp growth in the number of minerals processing plants as the world’s population both expands and becomes increasingly affluent, driving demand. As these plants age, supporting their continued operation will become increasingly vital.

Of the existing 550+ active minerals processing plants globally, 324 are over 10 years old and 212 over 20 years old, as shown in Figure 6 (SNL Metals & Mining 2015).

Aging equipment brings multiple challenges to the market. Chief among them is the need to keep them operating reliably. Mineral processing requires all elements to be working efficiently. A plant is constrained in its capacity by the stage in the process with the lowest efficiency, reliability, and availability. De-bottlenecking is the term used to identify and overcome these capacity-constraining steps.

Additionally, obsolete parts, items with long lead times, and parts that must be manufactured as “one-offs” can be disruptive to the operations of any plant.

Thickeners are low-maintenance, designed as critical equipment, and generally have no duty standby installed. As they age, more focus must be placed on them to allow continuous operation.

![Figure 6. Existing minerals processing plants and the year of establishment (SNL Metals & Mining 2015).](image-url)
3.3 Water Recovery

In previous sections, we discussed the environmental and social focus on mineral processing operations. As a water recovery system, thickeners can be targeted to meet new requirements in the recovery and reuse of water, ultimately reducing water consumed from the environment.

This environmental imperative can be met by increasing the underflow density of current thickeners. An increase in underflow density of 1% or 2% can return significant volumes of water to the operating plants. In Figure 7, each increase of 1% in underflow density reduces the amount of water to tailings by around 500,000 cubic meters per year.

3.4 Mineral Recovery

Thickeners that process valuable material can be referred to as product thickeners. These product thickeners, in duties such as such as concentrate dewatering and counter current decantation (CCD) washing, contribute directly to a plant’s overall metal recovery.

In concentrate thickeners, valuable material can be lost in the overflow if the thickener is not performing well, as shown in Table 1. Typically the feed is from the flotation circuit and a high level of froth is seen on the thickener. This froth carries solids into the overflow. Cases have been reported where solid concentrations as high as 2,000 ppm in the overflow. This material is valuable and failing to recover it at the thickener leads to lower overall concentrator metal recovery. Furthermore, it can result in additional costs in terms of reagents, damage to upstream and downstream equipment such as valves and pumps, and direct costs in process water tank cleaning as the solids finally settle in this tank. It is reasonable to expect 90% of the lost material from tanks and dams to be recovered. However, the last 10% (200 ppm) can represent an economically significant stream, so investments in improvements generate easy returns.

For most counter current decantation circuits a valuable component is present as a salt in solution. Any solids in the overflow may result in a decrease in the grade of the final product, and can add a large additional cost in solvent extraction (SX) plant maintenance or the need for additional filtration prior to the SX plant. Underflow density from each stage directly influences circuit washing efficiency and if the washing efficiency is not optimized then valuable metal will be lost to the underflow stream of the final thickener in the circuit.

Table 1. Quantity of lost concentrate in relation to recovery % and throughput.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solids to overflow ppm</td>
<td>2,000</td>
</tr>
<tr>
<td>Throughput m³/h</td>
<td>150</td>
</tr>
<tr>
<td>Concentrate in overflow per day kg</td>
<td>7,200</td>
</tr>
<tr>
<td>Recovery %</td>
<td>90</td>
</tr>
<tr>
<td>Lost concentrate per day kg</td>
<td>720</td>
</tr>
<tr>
<td>Lost concentrate per year</td>
<td>236.52</td>
</tr>
</tbody>
</table>
3.5 Impact
In the face of increasing demand and scrutiny, operators face many challenges. If incorrectly managed or addressed, they can directly influence the sustainability and, therefore, the profitability of an operation. These can be seen as:

- excessive consumption of chemicals
- increased water consumption due to losses to tailings or environment
- increased tailings storage facility costs
- excessive maintenance costs – direct and indirect (e.g. upstream instruments)
- recirculation of chemicals in the process water
- recirculation of already treated ore
- increased cost to replace obsolete parts
- lack of availability
- loss of license to operate
- loss of valuable product
- inefficient operation and process performance

4 Mitigation of Challenges
Confronted with these challenges, operators have several approaches available to them – purchase new equipment and plants, add new plants in parallel with the existing plant, or modernize the existing equipment.

The challenge of increasing capacity and changing ore may require replacement or parallel plants to be constructed. In cases where ore changes require not only increased capacity but different processes this may be the only option. Ore can change when the oxidized layer of the pit is exhausted and mining progresses into sulphide ores, or for other, less common, reasons. The benefit of parallel plants is that the original plant continues to be fully utilized providing no interruptions to customer deliveries.

When a capacity increase or changing ore can be processed by the existing plant, new equipment can be considered to address any identified bottlenecks. For thickeners, this is most often the outcome in cases where the existing tank size is not suitable when judged against thickener design rules (solids loading and/or rise rate). Alternatively, the age or condition of the thickener may mean that re-use of the tank and its support structure is no longer viable.

For an operating plant, expansion by “bolt on” equipment may seem an attractive option and considering the remote location of some plants, it would seem that footprint is not a significant issue. Two factors frustrate this assumption:

1. Installing new equipment at another location will entail changes to process flow, piping and electrification, which can significantly add to the project cost.

2. In many locations around the world, plants operate in a licensed area and any review or increase in this footprint may involve complex applications and compliance procedures.

The challenges raised by improved water recovery requirements or loss of metal production can also be met by new plant or equipment. In these cases, the operator is likely to be more interested in incremental improvements rather than large-scale capacity increases. It is therefore desirable to focus investments on directly improving the performance of the thickener through both operational advances and modernization.

When the existing tank satisfies the new requirements, modernizing the thickener is an attractive and often economically optimal method to extend the life of equipment or manage changed process scenarios.

5 Replace or Modernize
Investment choices are always a balance between the cost of investment versus the reward to achieve the necessary outcome, and the choice between thickener replacement or modernization is no different.

The first consideration should be the physical limitations of the existing tank, with the following typical questions:

- Will the proposed process parameters allow solids loadings and rise rates that provide suitable performance properties with the expected feed material?
- Is the condition of the tank and structure conducive to an additional 5, 10 or even 20 years of life and the higher loads expected?

Assuming the tank diameter and condition are suitable for increased loads, upgrades are possible to all other elements. Sidewall height can be extended, overflow capacity can be increased with new launders and/or new overflow boxes, floor angle can be increased, and underflow arrangements can be modified.

At this point, moving forward can become an economic decision and a cost comparison between replacement and modernization can be made. In this comparison the considerations are:

- time available for work — lost capacity during this stage can have significant cost implications
- social and regulatory licenses relating to land use
- cost of service provision to new thickeners

Modernization becomes an attractive option because it is encapsulated inside the plant boundaries and does not require new services, maximizing the use of existing plant
so capital efficiency is maintained or even improved. This provides operators with an appropriate solution to their changing process and plant requirements.

### Modernization Options

Modernization options range from completely replacing internals, utilizing only the original tank, to upgrading the automation systems for better control of the thickener performance. The most common upgrade options are presented in Figure 8. Recent work in the area of automation has demonstrated remarkable improvements in thickener stability, ease of operation, and overall costs.

Addressing thickener process issues will necessarily begin at the heart of the thickener – the feedwell. This is not always a simple case of installing a scaled-up version of the current feedwell; all elements of the feed system must be considered.

For old-style conventional thickeners, conversion to a High Rate Thickener (HRT) should be an early priority. HRTs allow for higher solids loading than conventional thickeners by efficiently using flocculation. Computational fluid dynamic (CFD) modeling and other research to improve the understanding of the complex and multiphase fluid flow behavior that occurs in feedwells [Heath & Triglavcanin 2010], has resulted in significant improvements in thickener performance and tolerance to varying flow conditions.

These same studies have shown that feed delivery to the feedwell must be controlled to optimize performance and control the elements required for good thickening to occur. Feed pipe size, elevation changes and dilution requirements all need to be considered in upgrading a thickener feedwell.

Often modernization will add weight, either due to larger or additional installed components as in the case of forced dilution. The impact of this weight on the bridge structure must be considered. The modernization may include reinforcing or replacing bridge elements.

Additionally, a review of the drive and mechanism for torque capability may be needed. When changing the underflow parameters, whether throughput, density or yield strength, and operating at the bed conditions necessary to achieve them, more torque may be required. Underflow changes can also require removal arrangements to be reviewed. Thickeners operating as gravity discharge may need pumping, while thickeners with underflow pumps may need larger or more appropriate pumps.

If an upgrade to the mechanical components is completed in parallel to the process improvements, then the mechanical challenge of availability, maintenance costs and obsolete parts can simultaneously be managed.

In the following sections this paper discusses aspects of contemporary thickener design, which can be applied to upgrades and modernizations of existing thickeners to suit increases in thickener throughput, changes in thickener duty or to improve process performance.

![Figure 8. Most common upgrade options.](https://example.com/figure8.png)
7 Feed System

Considered to be the ‘heart of the thickener’ the feedwell plays a primary role in overall thickener performance. The high-rate feedwell exists to provide an environment for proper flocculation. This plays a critical role in thickening through its function of improving the speed of solid-liquid separation and of gravity settling, especially of the finest fraction in the slurry. Distributing the material evenly into the thickener is also a priority function. As stated above, for the feedwell to perform its functions, the delivery of feed must be conducive to the process.

Therefore, a review of the design of the feed system for any change of duty will be critical to ensuring process performance targets are achieved. The aspects of thickener feed system design that can be addressed are discussed in this section.

7.1 Thickener Feedwell

Modern feedwells are referred to as high-rate due to their ability to allow a thickener to process material at a higher rate than conventional feedwells. High-rate thickeners are primarily defined by their efficient use of flocculant to aid in the settling of the feed solids. Introducing flocculants into the thickening process also introduces new demands for feedwell design.

In designing a feedwell for high rate thickening, it is important to control the amount of turbulence and fluid shear that occurs, as well as the area of the feedwell in which it occurs. This is critical to achieving good flocculation, capturing fine and coarse particles in flocculated aggregates without breaking those aggregates that are sensitive to excessive shear energy.

Modern feedwells are designed to utilize the feed momentum to control the mixing of incoming feed with flocculants and, in many cases, to introduce dilution liquor. Once particles have been successfully flocculated they must then be introduced into the bed of the thickener without tearing the aggregate apart. To achieve this it is necessary to dissipate momentum and energy as the flocculated slurry exits the feedwell. Even distribution into the body of the thickener is important to ensure the entire settling area of the thickener is utilized effectively. The fundamentals of a good feedwell design are presented in Figure 9.

Analysis and experience has shown that older conventional feedwells typically suffered short-circuiting (Nguyen, Heath & Witt 2006). This term describes a situation where feed plunges prematurely from the feedwell with poor mixing, flocculation, and energy dissipation. When a feedwell is experiencing short-circuiting the feed is not distributed evenly across the tank and it is common to see high levels of turbulence outside the feedwell and strong currents in the settling and clarification zones of the thickener. CFD modeling demonstrates short-circuiting as shown in the image on the left in Figure 10, compared with a modern feedwell as shown on the right.

In recent years some thickener technology suppliers have developed various new feedwell design concepts to meet the requirement of modern thickener feed system design discussed above. The Outotec Vane Feedwell™ design, shown in Figure 11, was launched during 2008 and has been at the forefront of developments in modern thickener feedwell design. It incorporates all of the necessary elements to optimize flocculant efficiency and improve thickener performance.

7.2 Feed Tanks

Situated externally and immediately prior to the thickener, feed tanks are used to prepare the feed for delivery to the feedwell to allow for efficient flocculation and formation of flocculants.

In many cases, processing plants are laid out such that thickeners are gravity-fed from an elevated position with pipes or launders running to considerable length and through multiple changes in direction, which tends to contribute to poor feed conditions. In particular, high velocity from launder flow and entrainment of air are common problems associated with gravity feed system
designs. In addition, multiple streams may be delivering feed to a thickener. The best designs currently combine flows into a single entry to the feedwell at a controlled velocity to provide the best flocculation conditions. An example of feed tank design can be seen in Figure 12.

Critical to designing an appropriate feed tank will be a thorough understanding of all potential streams, volume and solids loads, elevations, and the pipe layout prior to the tank.

Installing a properly designed feed tank can result in greatly enhanced thickener performance. The tank can act as the collector of multiple streams so that only a single pipe takes feed to the thickener. Baffles, shelves, tangential feeds and inverted outlet pipes are all used in innovative feed tank designs. These designs complement process improvements to allow a smaller-volume tank to be used, reducing the structural capacity required for installation.

![Figure 10. Short-circuiting in comparison with a modern feedwell.](image)

![Figure 11. Outotec Vane Feedwell™.](image)

![Figure 12. Feed tank design.](image)
7.3 Froth Control

Feeds with entrained air present a challenge to the flocculation process. Whether introduced as part of an upstream process such as flotation or inadvertently introduced in thickener feeds due to the pipe layout, air must be managed to allow flocculation.

Aerated thickener feed that makes its way into the body of the thickener tends to carry fine particles to the surface of the thickener to form froth. This froth causes issues such as the loss of product to thickener overflows (on product thickeners) and can cause a reduction in thickener underflow density due to poor flocculation. Higher maintenance time and costs can also be caused by wear and blockages through the accumulation of particles in process water, meaning that methods to alleviate froth on thickeners are required.

New thickener installations designed for slurry streams containing froth typically use conservative tank sizing. For modernization a larger tank is not an option. In all cases, it is preferable to manage froth before it reaches the thickener and this is a part of good plant design. In the absence of a feed tank or the space to install one, other options are available.

7.3.1 Baffles, Sprays and Booms

Installing a baffle in front of the overflow launder to hold back froth is a simple and effective froth control method. Combined with the addition of peripheral sprays to physically break up the froth, this solution can adequately manage light froth conditions. For peripheral spray systems, access to sprays for maintenance can be challenging and should always be considered.

For applications with a more tenacious froth, an enhanced arrangement would include using bridge-mounted knock-down sprays and rotating booms to transport surface froth under the sprays and break it down.

To fully utilize the benefits of a rotating boom, froth collection points can be included. The boom continues to transport the froth under the sprays for knock down, but the addition of the collection point removes a portion of the froth on each pass.

While these methods can be effective to a point and undoubtedly still have a role to play, experience shows that it is more effective to remove aeration from the feed and control feed velocity before it reaches the thickener feedwell.

7.3.2 De-aeration or Break Tank

Recognizing the importance of receiving thickener feed at the correct velocity and with minimal aeration, standardized feed conditioning systems have been developed. These systems have three functions:

1. Control the velocity to the feedwell
2. Provide full pipe delivery to the feedwell
3. Reduce or eliminate froth to the feedwell

These tanks can be designed to be externally mounted or bridge-mounted when situated inside the thickener footprint. The bridge-mounting solution is ideal as a modernization when the plant layout and site conditions prevent new feed tanks from being installed.

![Figure 13. CFD simulation results of thickener feed velocity break/de-aeration tank.](image)

The latest designs incorporate vortex-seeking dart plugs, tangential inlets and outlets, expansion chambers, and sprays. Once again, CFD modeling, as presented in Figure 13, plays an important role along with laboratory piloting and prototyping in various applications. Installations have been successfully completed in iron ore, coal and gold/copper sites.

7.4 Feed Dilution

The highest solids percentage by weight [w/w] of the feed slurry at which free settling of the particles can occur is selected as the target feedwell concentration and is determined by testwork. When the feed solids percentage is above the target concentration, the feedwell and feed system design must introduce additional process liquor to the feedwell to achieve the target. In high-rate feedwells, which utilize flocculants to agglomerate material, the correct feedwell solids density is crucial for the efficient use of flocculant. The correct dilution allows the flocculant to be able to freely disperse and to contact all of the solid particles.

As already discussed above, the trend of mining lower-quality ore bodies is resulting in finer material in thickeners. These particles have a higher surface area (per unit mass of solids) than coarser particles.
and a lower solids concentration within the feedwell is required to provide free particle settling and thus efficient flocculation.

Systems utilizing external dilution pumps, pipes and valves have now been replaced with less costly and more efficient internal dilution systems. In these systems, the clarified liquor on the thickener surface (also known as supernatant) can be directly utilized to dilute the feedwell slurry. There are several thickener feed dilution systems currently on the market.

7.4.1 Automatic Dilution

Automatic feed dilution systems were first introduced during the 1980s. When the bottom of the feedwell is largely closed off, the fluids on both sides of the feedwell wall remain at different specific gravities. As they are hydraulically coupled, the pressure equalizes and a geometric level difference exists between the supernatant liquor outside the feedwell and the feed slurry inside the feedwell as shown in Figure 14. In this system, gravity drives the dilution flow through openings in the feedwell as the slurry level inside is at a lower geometric level than the liquor outside of the feedwell.

Since the 1980s the best auto dilution technology has developed and is now able to introduce this supernatant liquor flow into the feedwell in the same direction as the incoming feed, promoting more effective mixing within the feedwell. This is referred to as directional auto dilution.

Additionally, the thickener geometry and use of the hydraulic head differential allows the degree of dilution to be naturally varied according to fluctuations in the density and flow rate of the feed. Hence, the best systems are able to buffer feed density variations, producing favorable flocculating conditions over a range of feed conditions.

7.4.2 Forced Dilution

In certain circumstances, it may not be possible to achieve the dilution requirements for a particular application using directional auto dilution systems. This includes applications where:

1. the specific gravity differential between the feed slurry and the overflow liquor is low, due to:
   - the particles in the slurry having a low specific gravity
   - low feed concentrations

2. high volumes of feed dilution flow are required to bring the incoming feed to the required density. This is commonly demonstrated when a high differential exists between received slurry density and diluted density.

To provide the necessary dilution in these cases, mechanical means are required. Figure 15 shows the forced dilution principle. Additionally, when the feed has a very high density, such as a thickener underflow, feedwell mixing becomes inadequate, additional mixing energy is required. Forced dilution can provide both dilution for flocculation and the energy required for mixing. Forced feed dilution systems have the disadvantage of requiring a power supply and adding some mechanical complexity. Fortunately, there is negligible wear on the rotating parts in such a low head pumping application.

The best forced dilution systems incorporate a design optimized for low head applications to minimize power requirements, shroud the impeller to ensure solids are not drawn into the feed, and introduce the dilution liquor in a direction conducive to the flow in the feedwell, assisting the mixing of flocculant with feed slurry in the feedwell.
7.5 Flocculant Delivery

When using flocculant, the preparation and delivery method must be carefully selected. Just as there is an optimal solids dilution, the flocculant must also be diluted to the correct level, which is typically 0.01–0.025%w/v. However, transporting diluted flocculant is challenging as any shearing effect greatly degrades the polymer chains. Best practice is to dilute to around 0.5%w/v at the flocculant plant, pump with a low shear pump, and then provide secondary dilution as close to the feedwell as possible.

The inclusion of bridge-mounted secondary dilution equipment can greatly increase flocculant efficiency, leading to reduced costs and improved settling. Properly designed secondary dilution can include static mixing, an open box for operator visibility and discharge lines optimized to prevent blockage.

8 Mechanical

Mechanical modernization of a thickener can be required for two purposes: process changes and mechanical condition.

Changes in process conditions that prompt a feed system upgrade can also affect the mechanical elements of the thickener. For example, if a larger feedwell is needed it is likely to be heavier than the original. This is especially true if the original feedwell lacked features such as multiple zones, vanes or deflector cones. New feedwells weighing in excess of 20 tons are now being installed. The age and condition of mechanical parts can be cause for an upgrade, or at least replacement of the affected parts. Many thickeners operate in harsh conditions, with salt and chemical attacks common, as well as general exposure to the environment.

When drive-line items reach the end of their life-spans, replacement with the latest technology is the best option. Notable among these are gearboxes, which have a design life of 10+ years. When the mine life is extended, even these durable components should be modernized in a planned way to coincide with other thickener works, rather than waiting for unplanned downtime.

Expansion, capital efficiency, and environment concerns often dictate that thickeners are required to provide a higher underflow density in addition to increased capacity. Even in cases with the same underflow density target, additional torque may be required due to rheological changes in the material. Drives up to 14.5 million Nm can now be installed when required.

All mechanical and structural components, including bridges, mechanisms and drives, must be capable of accepting these new loads.

8.1 Bridge

Full-span thickener bridges are designed to carry the vertical load of the rakes and feedwell, transmit the rake torque to ground, and provide lateral restraint when uneven loads are encountered in the thickened bed. When additional weight is added to the thickener during a modernization, a bridge review will be required.
In many cases, a reinforcement plan can be produced. Adding additional elements, such as braces, gussets or boxing in open sections, can provide the strength and rigidity required for a bridge to carry the loads of new equipment introduced for the modernization.

When bridges must be replaced, some innovative approaches have been taken. Full-span bridges can be replaced and installed according to the existing arrangement. However, in some cases it has proven a better solution to mount the new bridge on external support. These circumstances may include:

a. reorientating the bridge to meet a changed plant layout
b. reducing the cut-over time of the installation
c. suiting the current tank structure conditions

Modern bridge design allows some thickener upgrades by replacing an outdated center column with a full-span bridge. This has the added benefit of reducing the cost of the mechanism, drive, and operational maintenance.

Figures 16 and 17 show an upgrade where an old column design was replaced with a reorientated full-span bridge.

A section of the column can also be used as a steady pin, reducing the scope and cost of the upgrade in relation to underflow cone changes. A typical arrangement is shown in Figure 18.

8.2 Mechanism

The mechanism delivers rotational force from the drive and consists of a shaft or cage, rake arms and blades, and an underflow cone scraper. It must be able to provide this duty for any new conditions.

Rake arms and blades help to move thickened slurry inside the tank to the underflow cone and assist in dewatering. Underflow density is increased by gently shearing the bed to release water from individual flocculants and, on a coarser scale, opening up paths for trapped water, now liberated, to rise through.

Advances in design incorporating low profile arms, bolt-on rake blades, rotating pickets, bolted underflow scrapers or sectional steady pin and bearing arrangements, can all be included in the modernization project.

8.3 Drive and Power Supply

Drive units are required to apply torque to the mechanism. They typically consist of a multistage planetary gearbox, a power supply (hydraulic or electric) and a rake lift mechanism.

In all gearboxes, high pressure is created inside each meshing stage. This high pressure gradually removes metal from the meshing surfaces. The replacement life of these components can be predicted by regular oil analysis and inspections. However, the availability of spare parts for components that are 10 or even 20 years old may be the decisive factor in demanding a modernization.

Whether these drives are powered directly by electric motors or hydraulic power packs, the need for high reliability and availability will provide justification to consider replacing the power supply, either as a standalone upgrade or part of a broader upgrade strategy.
HPUs provide a reliable, low-cost power source as well as a simple way of monitoring torque.

A system to lift the rakes can be included in the drive unit to assist in managing high torque loads from the mechanism rotating in a thickened slurry. Raising the rake mechanism to bring the rake tips out of the mud, where most of the torque is generated, will provide temporary torque relief and additional time for operators to take action to reduce torque load and avoid thickener downtime due to “rake bogging”. Triggered by torque readings, rake lift can be powered by the same hydraulic power unit or an additional electric motor, depending on the primary power source.

Upgrades must involve reviewing the drive unit and it is vital to know the installed torque in order to assess the changes required to ensure the thickener is suitable for its new duty. When increased torque is needed, some drive modernization will be required.

8.4 Overflow

Overflow lip and launder systems draw supernatant liquor evenly from around the thickener and collect it in a single pipe. This uniform draw minimizes high, local rise rates and helps to provide a clean overflow.

Where a new duty has a higher volumetric loading, sizing of the installed launderers must be reviewed to ensure that they have capacity to manage any increased flows and remove the overflow liquor. If not managed, the liquor level may back up around the launder resulting in flooding and poor thickener performance. In extreme cases, there is a risk of uncontrolled liquor losses from the tank.

There are a number of options to remedy this scenario. In nearly all cases, the simplest solution is to install a second overflow nozzle. This will be located at 180 degrees from the existing overflow nozzle, provided launder depth is equal around the circumference of the thickener.

Alternatively, the launder depth can be increased by extending the weir plate allowing the thickener to run at a higher level. This can be best achieved when adequate tank freeboard is available, although the tank wall can also be extended as required.

8.5 Underflow Handling

The underflow cone and nozzles are the final withdrawal point for the thickened slurry. Removal can take place by gravity, which is common in South America where elevations permit, or by slurry pump.

As with the overflow considerations, the installed underflow nozzle(s) should be reviewed against the upgrade criteria for adequacy of sizing, considering the impact of slurry velocity and pressure loss in the pump suction or gravity discharge.

If underflow nozzles are undersized, it may be necessary to cut out existing nozzles and replace them with a suitably sized nozzle. Inline reducers are the simple response if smaller nozzles are required. Beyond the underflow cone and nozzles, the new slurry characteristic may necessitate a comprehensive review of the underflow arrangement through to the final destination. Sizing of all components, pipes, control valves and pumps must be included in the review.

9 Electrical and Instrumentation

The electrical components of a thickener are also subject to modernization, with replacement or upgrading to ensure ongoing reliability and operational performance. Increasingly, the trend is toward more automatic control of thickeners, and upgrading by installing modern PLC and higher-level control can produce demonstrable improvements in stability and performance.

Installed instrumentation should also be reviewed to ensure it is suitable for the process. The general operation and condition of the instrumentation, calibration, cleaning, and correct installation should all be checked. In many cases control of the thickener will be improved through installation of newer technology such as bed level instrumentation or a settling rate measurement device for control of flocculant dosing.

9.1 Control Panels

Control panels are vital for ensuring that operators can interact with the thickener. Historically, many functions of the drive unit were controlled using the local panel, whereas newer practice uses the plant’s distributed control systems (DCS) for machine automation – the local panel functions as a marshaling panel only. Still, most control panels are not able to modify process variables, but are used only to run the drive. Modernizing the control panel, either as part of a broader upgrade plan or stand-alone measure, ensures that the control panel meets current site standards and that all electrical components (such as PLCs) are still supported by their Original Equipment Manufacturer (OEM).

9.2 Bed Mass

Thickeners accumulate solids to create the bed pressure necessary to achieve dewatering. To establish this solids inventory it is necessary to operate with the solids
withdrawal rate below the solids feed rate for some period during start-up. Then, during steady state operation, the solids withdrawal rate should match the feed rate. To achieve this steady state of operation, it is desirable to measure both flows with a high level of accuracy, or to measure the solids inventory in the thickener tank.

Accurate mass flow reconciliation between inflow and outflow is difficult due to instrument error, leading to uncertainty. Fortunately, inventory can be indicated through a conversion of the output of a pressure transducer mounted on a purpose-built flange near the underflow withdrawal point of the thickener. Best practice has the sensor flush mounted to the inside of the tank. Any build up of solids forming a barrier between the bed and the sensor will reduce the accuracy of the reading.

Fitting, or replacing, a bed mass sensor should always be considered a modernization. Upgrading to newer models with hot-swappable capabilities should be considered to facilitate maintenance and ensure continuing reliability of the reading.

9.3 Torque

High levels of torque are required in modern high-rate thickeners due to design and operational improvements that allow increased underflow density targets. These torque levels can have catastrophic consequences unless control and protection systems are in place. Damage to mechanisms and bridges resulting in lengthy and costly repair can be avoided by installing, maintaining and operating to OEM recommendations.

9.4 Bed Level

Bed level is a crucial measurement to quickly detect rising solids. This may indicate flocculation problems or changed feed conditions which may result in poor settling, reducing underflow density and increasing overflow solids. In some control strategies, bed level can be critical for steady state control and is commonly used in a control loop for flocculation.

It is important to note that process-specific considerations dictate which type of instrument to use and regular maintenance is always required. Modernization will typically involve replacing preselected, poor-performing types and ensuring maintenance access is simplified.

9.5 Underflow Density

Achieving the target underflow density is a major Key Performance Indicator for a thickener. In conjunction with the bed mass measurement the underflow density must also be measured. The relationship between bed mass and underflow density tells an experienced operator the efficiency of the dewatering of the thickener. Manual measurements are suitable in some applications but online measurement is generally recommended and can then be used in automated thickener control.

While a range of instruments are available for this application, gamma radiation based instruments are the industry standard and are widely available. During modernization, a review of the suitability of old radioactive sources is warranted as detector sensitivity has increased so that even old sources can be reused.

Density instruments are commodity items and instrumentation sales personnel may lack process understanding for thickener applications so during modernization support can be provided by the OEM.

<table>
<thead>
<tr>
<th>Local regulations must be consulted for nuclear source management, but the following general principles apply:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Use modern detectors to ensure the source has as low an activity as practicable, re-use old sources to minimize disposal/storage risk</td>
</tr>
<tr>
<td>2. Position the source such that gamma radiation is directed away from walkways or provide shielding for personnel</td>
</tr>
<tr>
<td>3. Schedule radiation leak tests with meter surveys and wipe tests</td>
</tr>
<tr>
<td>4. Limit access to the area, in particular the last 1m</td>
</tr>
<tr>
<td>5. Maintain records of sources on site. (In use or in storage)</td>
</tr>
<tr>
<td>6. Install necessary signage</td>
</tr>
</tbody>
</table>

Figure 19. General principles to consider for nuclear source management.
10 Automation

As with any automation project, thickener automation begins with process control. High density is the desired result from most thickeners and is a useful performance metric for any control.

Figure 20 approximates what can be seen when considering hourly average density data over a month of constant production (i.e. without shutdowns). And while each hour’s density result is not strictly independent, for a qualitative assessment, each data point can be considered to be independent.

Improving process control and ensuring stability, tightens the distribution of the controlled metric from grey to blue. Once tight control has been achieved, the optimization phase can begin. This is demonstrated with the move from blue to green.

The control of a thickener includes the measurement of variables outside of the thickener footprint. Underflow pumps and flocculant dosing pumps must be manipulated as shown in Figure 21.

Typically, thickener controls are implemented as single loop controllers in DCS/PLC systems. These systems are challenged by long response dynamics and interaction between variables, leading to difficulties in maintaining the desired operation point in varying situations and quality targets not being consistently met.

Whilst some classical techniques can handle these situations, regular operator intervention is required. The tuning becomes difficult, typically requiring high-level experts to remain onsite. Another challenge is in allowing for process constraints and the desired prioritization between controlled variables.

Figure 20. Typical histogram movement as outcome of optimisation and control project. Step one tighten the distribution of the controlled metric from grey to blue. Step two maximise the average of the controlled metric from blue to green.

Figure 21. Underflow pumps and flocculant dosing pumps must be manipulated to control the thickener.
Introducing Automation Control Tools (ACT) overcomes the inability of Proportional, Integral, Derivative (PID) loops to handle slow response dynamics and cross actions between controlled variables. An appropriate control system architecture is required and an example is shown in Figure 22. Here, the advanced control calculations can take place on an Higher Level ACT system that sits above the site’s process control system (PCS). A similar architecture is used across a range of advanced control solutions. Separating advanced control from sequences and the general human machine interface (HMI) on the PCS makes both systems easy to maintain and troubleshoot.

Figure 23 shows the results that have been achieved after installing ACT-based advanced control on a concentrate thickener. Of interest is the fact that the tuning period was completed within only 1 week of onsite step tests. This compares favorably with PID based approaches that can take many months to fine-tune to an acceptable level of performance.
11 Outotec Solution

Designing and executing modernizations to a thickener to meet new process and plant conditions requires deep and thorough investigation. The impact of process conditions must be considered holistically for the impact on each element of the thickener. Testwork and process or even plant audits may be required. In addition to confirming operator requirements, these broader studies may also highlight complimentary or alternative actions that are required to achieve the process requirements. Audits often reveal that feed delivery routes and filtration plants require further investigation.

In some cases, the result of an investigation may reveal a wholly different solution. Where filter performance is tightly coupled with thickener performance, installing a suitable filter feed tank to decouple the unit processes may offer a more effective solution than a thickener modernization.

Outotec began upgrading thickeners in 1989 and has successfully managed over 140 major upgrades globally. The timing of these upgrades is shown in Figure 24.

11.1 Methodology

Successful delivery of an upgrade is a collaboration between the customer and Outotec. Ultimate success is based on a broad and proper understanding of the current and future situation, the goals of the client organization, and the physical assets available. The more work and commitment in the early stages, the better the quality of the outcome.

Outotec works closely with the customer to identify the success criteria of the planned modernization. Understanding the key requirements of the upgrade – the “what and why” – will ultimately ensure a successful outcome for all parties.

Using a suite of tools including site audits, testwork, engineering studies and the latest design programs, a thorough information-gathering exercise is undertaken. The specifics of the original equipment design, both mechanical and process, are captured for the current and future requirements of the thickener.

11.1.1 Desktop Review

Information is critical to the success of an upgrade. To begin the process, the thickener performance requirements must be known. A desktop review of the process is then conducted to determine the suitability of the thickener tank for the required duty.

Critical questions answered here relate to the basic thickener requirements of solids loading and rise rate. Outotec will utilize its extensive database of installed thickener design criteria and draw on industry-leading expertise to ensure the thickener size is suitable for the duty requirements.

![Figure 24. Outotec thickener upgrades globally.](image-url)
The outcome of this stage may include:

1. a report of findings
2. preliminary scope of options
3. price indications
4. firm pricing for testwork, site inspections and engineering studies if required

11.2 Testwork

Accurate characterization of the settling properties of thickener feed is best achieved with thickener-specific testwork. Outotec has developed a method of conducting dynamic thickener testwork using a lab-scale thickener that, compared to traditional cylinder settling tests, is more representative of the conditions present in a full-scale thickener. This includes the effects of a rotating rake mechanism as well as the continuous up-flow of liquor inside the thickener. It is also possible to withdraw samples of thickened underflow to measure their rheological properties. The test rig is shown in Figures 25 and 26.

A benefit in brownfield plants is that representative ore is more likely to be available than during testwork for greenfield development. This ensures a more accurate understanding of the settling and thickening characteristics of the material. Testing can also be carried out on-site alongside an operating thickener.

This on-site testing yields particularly valuable information when a site is auditing or troubleshooting thickener performance. Carrying out the testing on-site also provides benefits in applications where aging of material during transport and handling can render the sample unrepresentative. On-site testing can also make it easier to test under a variety of conditions as in reality many operations will receive run of mine (ROM) ore from multiple locations [Bickert 2012].

Testing provides an indication of the thickening performance that would be achieved with the material tested at optimal loading conditions and comparatively at conditions expected in the existing tank. These may not be the same due to the fixed diameter of the existing tank. This information is vital for the operator to understand what can be expected and how this influences plant throughput and design. It can directly contribute to the decision to purchase new equipment or modernize existing equipment.

The test results provide information for feed system design requirements, such as the optimal solids concentration at which material flocculates. This is important for designing the feedwell and dilution system and establishing the flocculant dosing rate.

Satisfactory testwork results are also used as the basis of any process performance guarantees that may be required for the upgraded equipment.

Once this has been done and outcomes agreed, work moves forward to establish the final scope. At this point, access to detailed information on the existing thickener design is required.

11.3 Engineering Review

An engineering review collates the available mechanical information, proposed process changes and thickener information to establish broad parameters for detailed engineering and drafting to commence. An engineering review will typically allow a firm price to be provided.

There is often some difficulty in collecting the required level of engineering detail. Old drawings may be inaccurate, lacking complete information, or they may not exist at all, necessitating an engineering survey. This can be conducted by either the client or Outotec. Developments in laser scanning can replace some of the survey requirements, enabling a faster time to realization of the necessary detailed information.
During the engineering review, consideration of the mechanical components is paramount. To upgrade a thickener for improved process performance but then have it constrained in performance by a mechanical limitation would be undesirable. The customer needs to have a clear understanding that changing or introducing new elements to meet the process requirements can require enhancement of the mechanical elements. As detailed earlier, both static (mass loads) and dynamic (torque) requirements can increase when a feedwell is upgraded. An engineering review will provide the plan to address these needs and allow for firm pricing of the prerequisite work.

11.4 Design Considerations

At this stage, consideration must also be paid to interfaces with any existing equipment. If the current bridge support structure is sufficient for the new feedwell, for example, how will the new feedwell and other items attach?

The design consideration would also include:

- transport windows
- seismic and wind loads
- localized material and electrification requirements

11.5 Final Design

At the conclusion of this work, a clear scope of modernization is available, with expected outcomes agreed and a final package of information presented to the client including:

- firm pricing
- delivery schedules
- general Arrangement (GA) drawings showing interfaces
- process guarantees and installation methodology may also be included

This process may consume some time, but is vital to understand the process and progress methodically to achieve the outcomes for the operator. Making an effort in the early stages ensures success and a faster ramp-up for new production needs.

Modernizations allow the owner to continue to operate thickeners beyond their initial design parameters or life in a capital-efficient and environmentally sustainable manner.

Depending on the stage of the cycle and the specific plant requirements, upgrades may focus on processes, mechanics, electrics or automation, or a combination of these.

As a pure economic exercise, there is no doubt primary motivation will be plant capacity increase, followed by changes in thickener feed (changing ore conditions). In some locations, water utilization alone can provide economic sense if the water cost is in the range of USD 1–3 per cubic meter.

Modernizing a thickener to accommodate process changes or to provide improved performance centers on installing the latest in thickener feedwell technology.

Modernizations centered on mechanical or electrical needs ensure that thickeners can continue to operate reliably and efficiently, providing risk mitigation and continuity of service. Automation upgrades can directly contribute to plant efficiency and bottom-line performance with greater control over the equipment.

Implemented correctly, an upgraded thickener can perform to the same level of a new thickener by incorporating all of the latest technology advancements to achieve one or more of the following benefits compared to older designs:

- Reduced flocculant consumption
- Improved overflow clarity
- Increased underflow density
- Maximized water recovery
- Reduction in required thickener area for a given throughput
- Improved controllability
- Ability to operate effectively over a range of operating conditions

As one of the world’s leading technology suppliers to the mining industry, Outotec is positioned to assist operators in achieving plant capacity increases, managing varying ore properties, improving process performance, and meeting equipment availability goals by modernizing existing equipment.

12 Summary

Mine owners today, as always, face numerous challenges. Changing ore characteristics, aging equipment, social and environmental considerations all affect how plants are operated. Ever-increasing demands for capital efficiency and more sustainable methods see owners pushing process equipment to levels never envisioned by the original plant designers.
References


SNL Metals & Mining, [2015].

Outotec provides leading technologies and services for the sustainable use of Earth’s natural resources. As the global leader in minerals and metals processing technology, we have developed many breakthrough technologies over the decades for our customers in metals and mining industry. We also provide innovative solutions for industrial water treatment, the utilization of alternative energy sources and the chemical industry. Outotec shares are listed on NASDAQ OMX Helsinki. www.outotec.com