Designing for Paste Thickening
Testwork and Sizing for Paste Thickeners

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Abstract

In the mineral processing industries, there is an increasing need to design thickeners which are able to produce high density underflows usually referred to as "paste".

The behaviour of a flocculated suspension in compression needs to be well understood in order to arrive at a reliable thickener tank configuration (i.e. diameter, cone angle and depth) for a required paste result.

As a suspension approaches paste consistency, its fluid characteristics change markedly. It develops a high yield stress, and may have an increased tendency to form agglomerates, which in thickener tanks leads to a phenomenon known as "rotating beds", "donuts", or "islands". These characteristics present challenges to the designer of the rake mechanism.

The subject paper addresses the requirements for designing a paste thickener, covering the following topics:

- Testwork for thickener sizing.
- Design of rake mechanisms.
- Suspension rheology and effect on design.

1. Introduction

Thickening slurries to the maximum possible density (paste) is becoming increasingly common. Applications such as Autoclave feed thickeners, paste backfill and some counter current washing (CCD) circuits are all examples of potential paste thickening applications. The principle of paste thickeners is that the compression zone is much deeper than on either high rate (HRT) or high compression (HCT) units; generally 3 metres or more. As the compression zone gets deeper, the underflow density for a given flux rate (tph/m^2) increases, as a result of two factors:

- Longer bed settling time. Settling flocs move relative to one another and release interstitial fluid when they are in compression. Increasing bed residence time achieves higher density underflow as more fluid is removed.
- The net weight of the bed creates a compressive force on the settling flocs. This force increases with depth, so that the flocs at the bottom of the bed experience the highest compressive force. This represents the driving force to expel interstitial fluid and hence increase bed density.

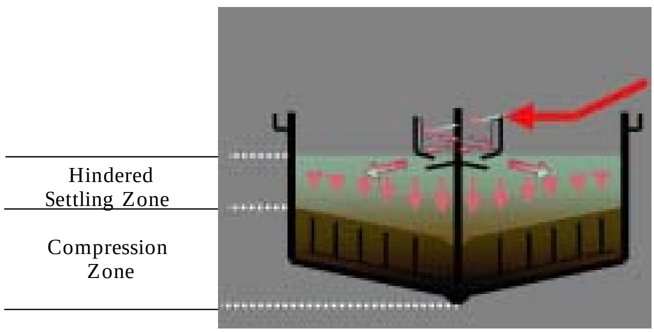

Figure 1: Thickener zones.

These two factors work together to increase pulp density, but it is generally not possible to separate the effect of each factor in a dynamic situation.

One of the challenges with paste thickening applications is the accurate testing and thus sizing of the units.

2. Test Techniques

For the sizing of high rate and high compression thickeners, dynamic bench-scale or pilot-scale testwork is the preferred approach. However, static cylinder testwork and the application of the Talmage and Fitch construction is still sometimes used.

The advantage of dynamic testwork is that a reliable relationship is established between the solids flux rate, underflow density and overflow clarity. The other significant parameter is flocculant dosage, and some attempt is usually made to optimize this as well.

It should also be understood that if the solids flux rate changes (i.e. an increased feed rate and underflow withdrawal rate for a given cross-sectional area), the liquid rise rate also changes, resulting in a different bed dynamic and a variation in the settled density.

Figure 2: Bench-scale 94 mm high rate thickener.

When considering paste testwork, the additional bed depth used can be a problem as a much larger sample is required. To avoid this, recent attempts have been made to define a parameter termed "unit mud volume" for scale-up purposes.

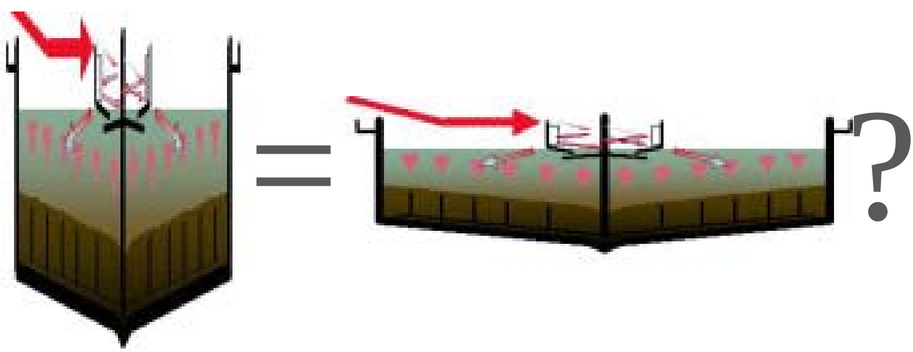

Figure 3: Is "unit mud volume" a useful parameter?

Unit mud volume is defined as "*the volume of thickener bed (mud) required to achieve a given underflow % solids at a throughput of 1 tonne per hour of dry solids*".

For example, a laboratory or pilot-scale test unit might be operated to give a desired density at a flux rate of 0.3 t/m^2h and a bed depth of 2 m, giving a "unit mud volume" of 6.67 m^3h/t (bed depth/solids flux rate).

This parameter is then used to calculate the required bed depth at a significantly higher flux rate, e.g. 6.67 m depth at a flux rate of 1.0 t/m^2h. The problem with this approach is the need to extrapolate from one flux rate to another without having data on how the higher flux rate will affect the settling characteristics of the flocs.

To illustrate this further, the graph below shows the relationship between "unit mud volume" and solids flux rate at a constant underflow % solids for a copper tails sample:

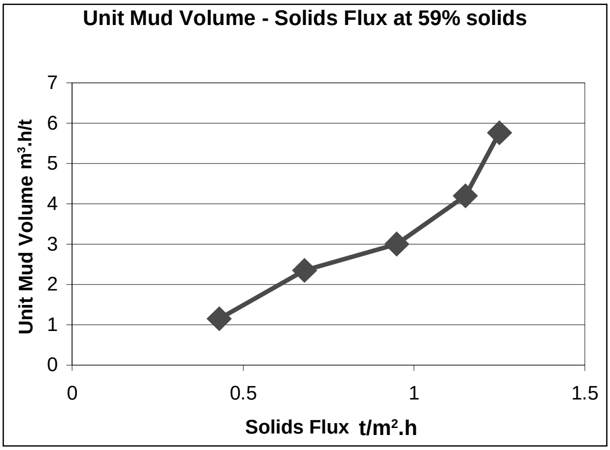

Figure 4: Unit mud volume vs solids flux.

We can see that the unit mud volume varies, in fact, increases, as the solids throughput of the thickener increases.

The graph below shows the corresponding relationship between solids flux and bed depth.

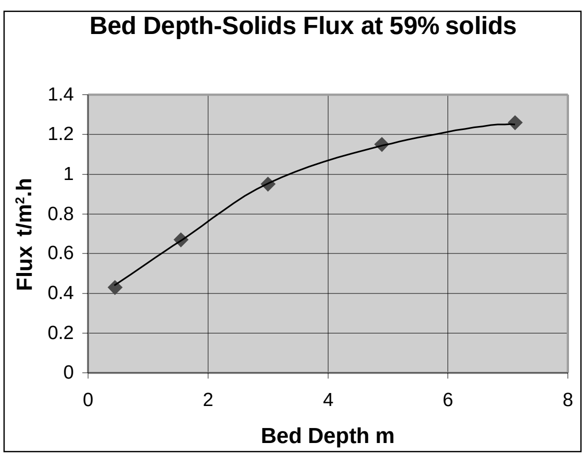

Figure 5: Bed depth vs. solids flux at 59% solids.

Taking the simple example of a thickener with an area of 1m^2 we see from the above graph that to treat 12 tpd (0.5t/m^{2}h flux rate) and produce a 59% solids underflow, we would require a mud bed depth of approximately 0.72 m.

Increase this throughput to 24 tpd (1.0t/m^{2}h flux rate) and the required bed depth increases to 3.36m to produce the same 59% solids.

This represents an increase in bed depth of nearly 5 times.

Finally, take another slightly higher throughput of 30 tpd (1.25t/m^{2}h flux rate) and the required mud bed depth increases to approximately 7 m.

Using the constant unit mud volume idea would suggest that the bed depth need only increase from 0.72 m at 12 tpd throughput to 1.8 m deep at 30 tpd throughput.

Quite clearly this would create a situation where the required density of 59% solids would not be achieved.

Another way to review the data is to consider bed depth vs % solids, graph below. This figure indicates that an increase in bed depth allows either an increase in the % solids of the underflow or an increase in the throughput at a given underflow density.

Clearly these relationships are not linear and show a tendency to some maximum as bed depth increases. This illustrates the diminishing returns available from each increase in bed depth, again illustrating that the constant unit mud volume concept is flawed.

What this analysis clearly shows is that increasing the mud bed depth does provide a degree of control over the thickener underflow performance. Deeper beds can be used to optimize the underflow density at a given throughput or optimize the throughput at a target underflow density.

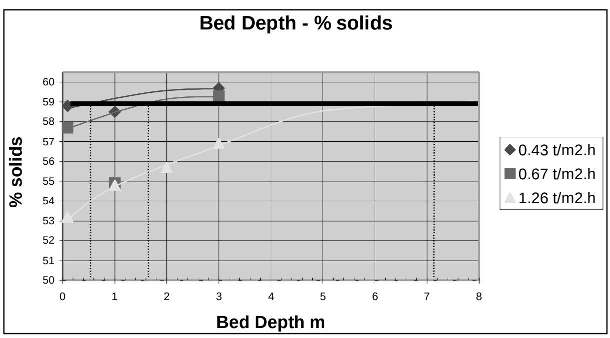

Figure 6: Bed depth vs. % solids in the underflow for different flux rates (t/m^{2}h).

What is also highly evident is that the mud bed volume for a given material is not constant. It depends upon the solids flux rate and target underflow density. As one would expect, the unit mud volume required to achieve a given underflow density increases as the thickener throughput increases.

This also leads to the conclusion that, inconvenient as it might be, the only reliable way to predict underflow density for a given flux rate and bed depth is to run small-scale tests at the flux rates and bed depths required. Since a difference in actual paste thickener performance of 1 or 2% in density can be crucial in some applications, a very limited amount of extrapolation is usually acceptable.

3. Paste Testwork Approach

It is very often the case, e.g. for greenfield projects, that limited sample is available to carry out thickener testwork. Hence, our approach would usually be to carry out initial testwork in a bench-scale high rate thickener rig to establish the primary settling characteristics.

These would normally include response of underflow density and overflow clarity to flocculant type, feed dilution, flocculant dosage and solids flux. Typically, with a sample size of around 10-12 kg of solids, a set of curves in the "high rate" mode can be generated as per below:

Armed with this information, a set of operating conditions can be selected and one or two tests conducted in a "deep bed" test rig.

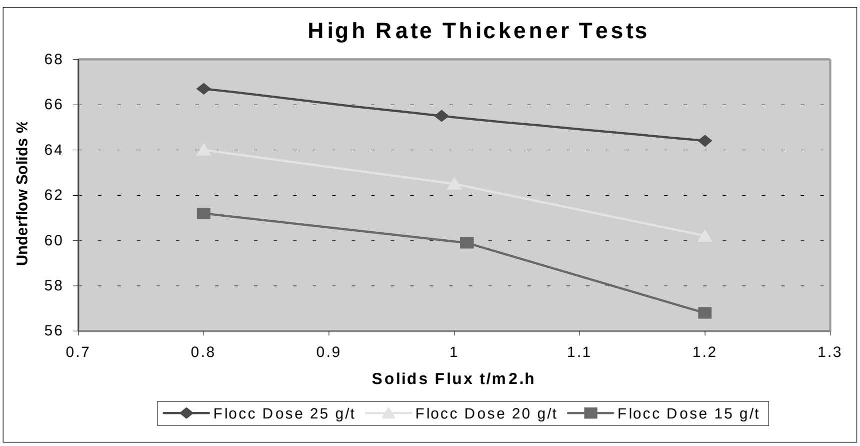

Figure 7: High rate thickener tests.

Below Figure 8 shows laboratory-scale units with a diameter of 190 mm and a height of up to 4 m.

It has been established, after numerous comparative lab tests, that with the 190 mm diameter unit, the "wall effects" are negligible, and results equivalent to pilot scale are achieved.

Figure 8: 190 mm dia. test rig.

The data obtained from these rigs can be represented as per the graph below.

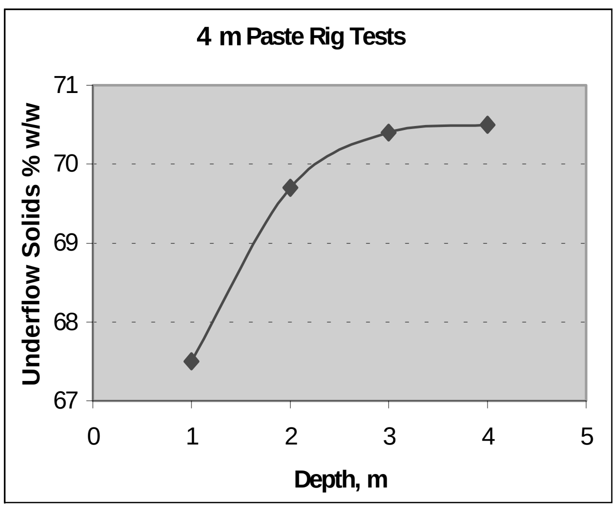

Figure 9: 4 m paste rig tests.

When underflow samples are taken from this rig, a vane rheometer is used to characterise the underflow material.

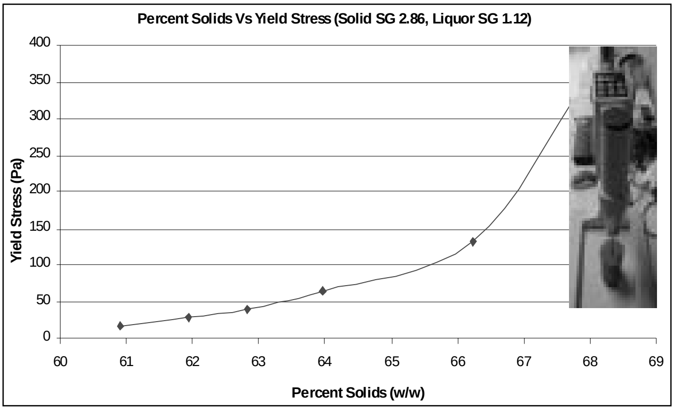

Figure 10: Percentage solids vs yield stress.

These rheology measurements provide an important means of determining the practical configuration for a paste thickener on scale-up, including the mechanism and drive requirements. The flux rate / bed depth / underflow % solids data are used to determine tank diameter and depth.

The concept of a constant unit mud volume appears to be very attractive when scaling up thickeners. However, the reality is that the unit mud volume is neither constant nor predictable at different throughput rates. Testing at the desired throughput and bed depth conditions is the only way to reduce the risk associated with scaling up paste thickeners.

Simply put – increasing bed depth has a diminishing return.

4. Sunrise Dam Gold Mine (SDGM) – R&D Programme – Gold Tailings Thickener

4.1. Rotating Agglomerated Mass

Before looking at mechanism designs, a quick look at this phenomenon.

Thickening with flocculant of some ores results in the phenomenon of rotating agglomerated masses – sometimes called islands, donuts .... This rotating mass within the thickener is detrimental to overall thickener performance due to the loss of effective dewatering area and also results in higher operating torques and lower underflow densities.

We have noticed that as thickener underflow density limits are pushed the likelihood of rotating masses increases. In conjunction with higher densities comes higher installed torques, dewatering rods or pickets and higher beds covering more of the mechanism. All of these lead to larger projected areas of steel pushing through more compacted beds and if the solids have a tendency to agglomerate and rotate then these factors will add to this tendency.

Figure 11: Video of rotating bed phenomenon.

The above video is of Outokumpu's 94 mm dynamic lab scale test thickener. The material was from AngloGold's Sunrise Dam Gold Mine in Western Australia. SDGM has an existing Outokumpu 24 m diameter High Compression thickener – Figure 12.


Figure 12: SDGM 24 m high compression thickener.

SDGM contacted Outokumpu in regard to lower than desired underflow densities coupled with problematic thickener operation. Outokumpu perceived that the poor overall performance was due to the tendency for the material to form a rotating bed when higher underflow densities were targeted.

A Paste Thickening R&D Programme was agreed to and completed in 2003 at SDGM based on an agreement between AngloGold and Outokumpu.

Outokumpu used a 2.4 m diameter pilot thickener – Figure 13 - to assess the performance possibilities of the ore being treated.

2.4 m being largest possible to be in-gauge road transported.

Figure 13: 2.4 m pilot thickener.

From a design of mechanism point of view, the objectives of the R&D program were;

- To confirm that a rotating bed would be formed in the pilot thickener.
- To compare and optimise the relative effectiveness of different rake configurations for rotating bed prevention.
- Determination of k factor (torque) versus unsheared yield stress.

5. Rotating and Static Pickets

From a series of preliminary tests, it was established for the 2.4 m test pilot thickener that a combination of eight stationary and four rotating pickets, as shown in Figure 14, at a rake arm tip speed of 11.3 m/min provided the most effective rake mechanism, ie preventing rotating bed formation, providing adequate dewatering and compaction and permeability of the bed.

This results in improved underflow density and lower flocculant consumption.

Figure 14: 2.4 m pilot thickener rotating and static pickets.

6. SDGM Pilot Results vs. Plant Results

The next phase of the test programme was to collect comparative data from the 2.4 m pilot thickener and the 24 m HCT on a daily basis.

The 2.4 m pilot thickener was operated at similar and different conditions to the plant thickener however the common element for tests 5 to 25 is that bed rotation was prevented. It is clear from the Figure 15 below that the 2.4 m pilot thickener provided higher underflow densities for all except one of these tests when compared to the 24 m HCT.

The one that did not provide a higher result was test 6. This was a test which investigated high rake tip speed with a full complement of rotating pickets. Hence a limit was established for rake speed with this rake configuration.

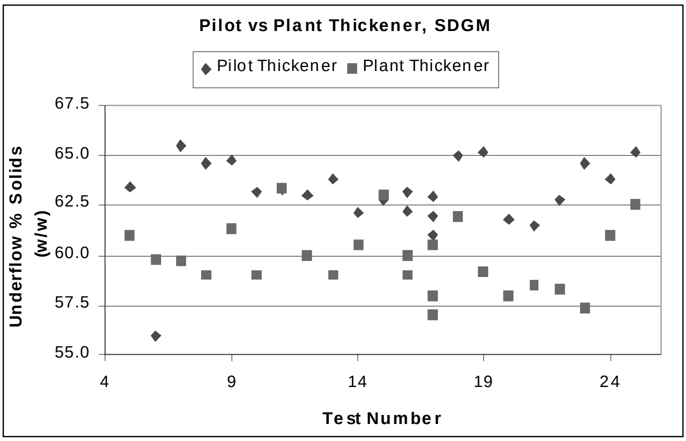

Figure 15: Comparison of 2.4 m pilot thickener & 24 m HCT underflow densities.

In summary, the 2.4 m pilot thickener achieved the objectives of the R&D programme in forming and then preventing the formation of a rotating bed and consequently obtaining increased underflow densities at reduced flocculant dosage rates.

It was concluded in the 2.4 m pilot thickener that a combination of eight stationary and four rotating pickets at a tip speed of 11.3 m/min provided the most effective rake mechanism. That is, preventing rotating bed formation, providing adequate dewatering, compaction and permeability of the bed. This led to improved underflow density and lower flocculant consumption.

7. Yield Stress (SDGM Material)

Yield stress is an important parameter and was tested extensively throughout the R&D programme.

The results indicate that higher underflow densities could be achieved, however, consideration needs to be given to thickener drive torque rating and pumping of the underflow due to higher yield stresses.

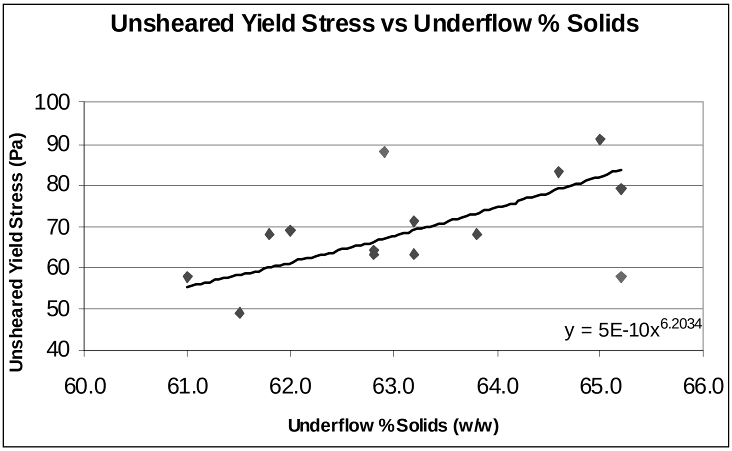

Figure 16: Yield stress vs underflow % solids.

8. Shear Thinning (SDGM material)

It was found that a centrifugal underflow pump would approximately halve the yield stress of the underflow.

Before Centrifugal Pump (Pa)	After Centrifugal Pump (Pa)
79	50
68	31

Table 1: Before and after pump yield stress.

The Haake Viscotester VT550 was used to see if it could reproduce this type of shearing event. The Haake program was modified to initiate two stages of shear thinning. These results were recorded as “1 x shear” and “2 x shear”.

Yield stress is determined by recording the peak of a shear stress versus time curve. The unsheared yield stress was calculated at a shear rate of 0.1 s-1 over 60 s. The Haake was programmed to then rotate the vane at a high shear rate of 10 s-1 over the next 60 s period – shearing event – and then back to 0.1 s-1 over 60 s to measure the yield stress after this event. This was done twice.

Before Pump (Pa)	Simulated 1 x shear (Pa)	Simulated 2 x shear (Pa)
79	29	20
68	33	25

Table 2: Simulated shearing events.

Also tested were the effects of using a centrifugal pump to recirculate underflow in the underflow cone of the thickener.

Unsheared Yield Stress (Pa)	Yield Stress (Pa)
58	23
88	41
69	37
91	62

Table 3: Unsheared and recirculated sheared material.

Correlation here is not accurate and data limited however does show that the Haake can be used to simulate shear thinning.

More definitive work is warranted and could be extended to include positive displacement pumps and effects of pipeline transport.

9. Operating Torque vs Underflow % Solids (SDGM material)

As the underflow % solids and hence unsheared yield stress increased the operating torque also increased.

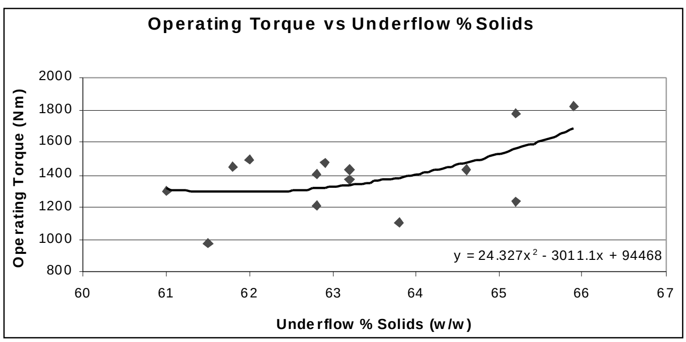

Figure 17: Operating torque vs underflow % solids.

10. k Factor

An ‘industry’ standard formula that is used to determine thickener drive capacity is;

Max Operating Torque (Nm) = 14.63 x k x d2

d = thickener dia. (m).

With k varying depending essentially on material characteristics at the desired densities and the level at which the drive is to operate for normal conditions.

Normal operating torque can be say 33% of maximum operating torque, or a more conservative approach would be 25%.

Following graph is based on operating torque being 25% of max operating torque and based on SDGM testwork.

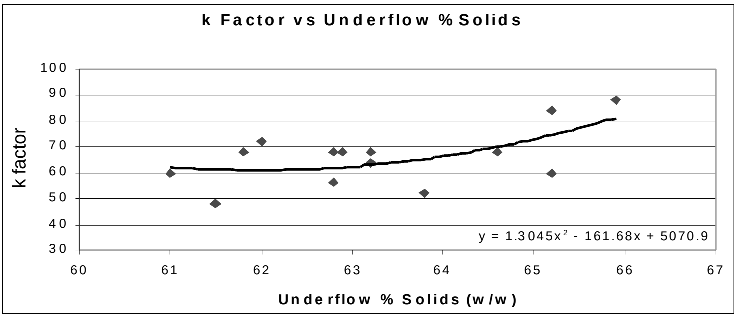

Figure 18: k Factor vs Underflow % Solids.

11. Evolution of Rake Mechanism

The original Outokumpu High Rate thickener mechanism consisted of drive shaft, two long arms, two short arms, both with strut supports and tie rods “tying” the four arms together. This is still the “standard” for conventional and High Rate applications and is shown in Figure 19.

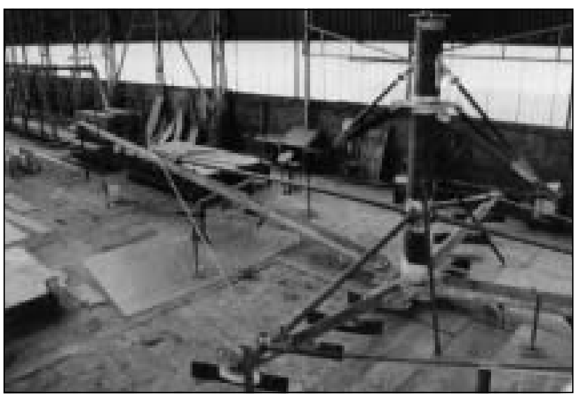

Figure 19: Geita 25 m HRT (1998).

For higher density applications, higher and higher torque mechanisms were introduced with wall heights and floor slopes increasing but not necessarily diameter. This is shown in Figure 20.

Figure 20: Comalco Alumina Refinery – 22 m Paste Thickener (2004).

Then the need for dewatering pickets entered into designs to assist in extracting that extra couple of percent underflow density.

Rotating dewatering pickets provide a channel for the water to move upwards through the compacted bed. This can be seen in Figure 21.

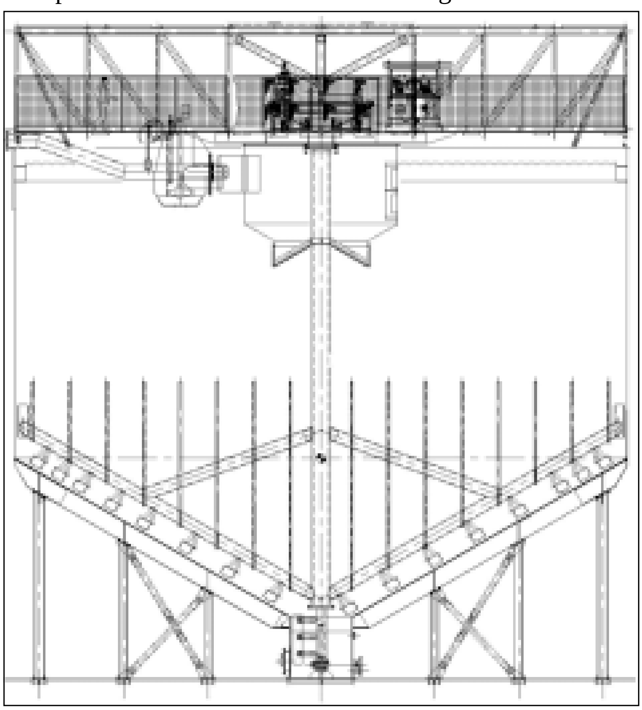

Figure 21: Goro 20 m Paste Thickeners (2004).

Next was the possible need to include static pickets to prevent rotating beds. This is shown in Figure 22.

Problem – struts are right in the main central zone where static pickets are most required. Solution – eliminate the struts.

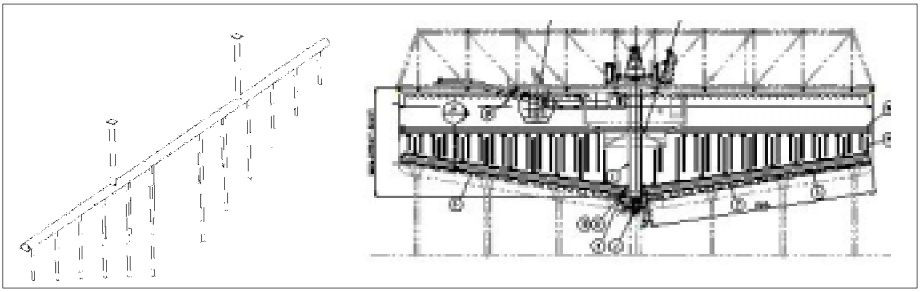

Figure 22: Proposed Static and Rotating Picket Arrangement for High Compression Thickeners (2004).

Finally – Paste Thickeners requiring all components and concepts in one, i.e. maximising bed depth, floor slope, torque and dewatering as can be seen in Figure 24.

Figure 23: Typical Paste Thickener - Pajingo 14 m PT (2003).

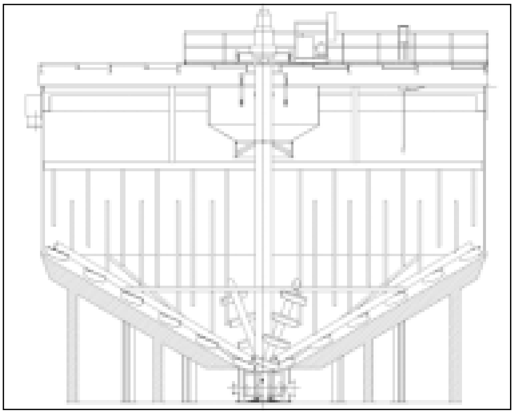

Figure 24: Aguablanca 16 m diameter Paste Thickener High high torque, rotating pickets, no struts and static pickets.

The Aguablanca testwork showed a strong tendency for the bed to rotate and it was decided to include static pickets.

Design was for rotating pickets for maximum dewatering, no strut mechanism (Figure 25 & 26) and the inclusion of static pickets.

Figure 25: Rotating pickets at Aguablanca (2004/2005).

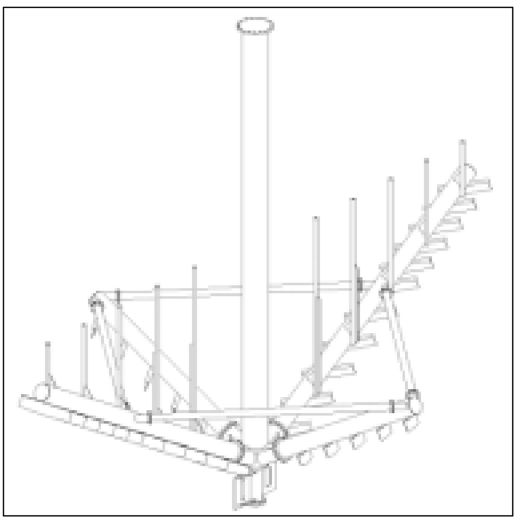

Figure 26: Aguablanca 16 m PT Mechanism (Static Pickets not shown).

12. Bogoslovsky Alumina Plant

16 m Paste Thickener located in the town of Krasnoturyinsk (Russian Urals). Final red mud tailings thickener after washing. Original unit – Figure 27 - was an

old multi-tray thickener which Bogoslovsky wished to replace with a new paste thickener – Figure 28.

Due to be commissioned mid-late 2005.

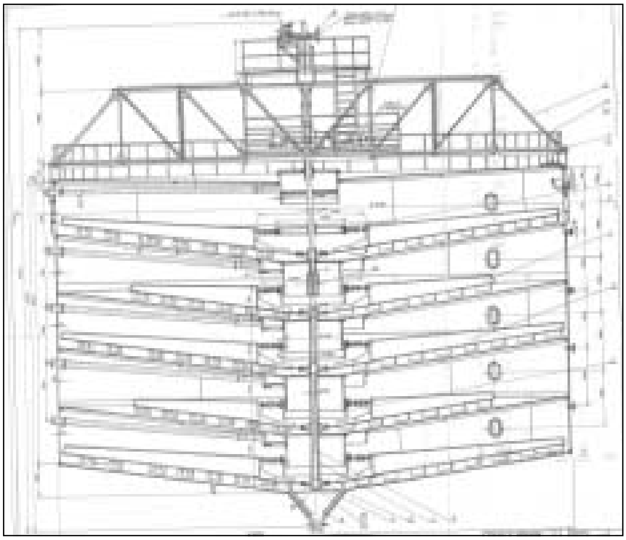

Figure 27: Bogoslovsky original tray thickener.

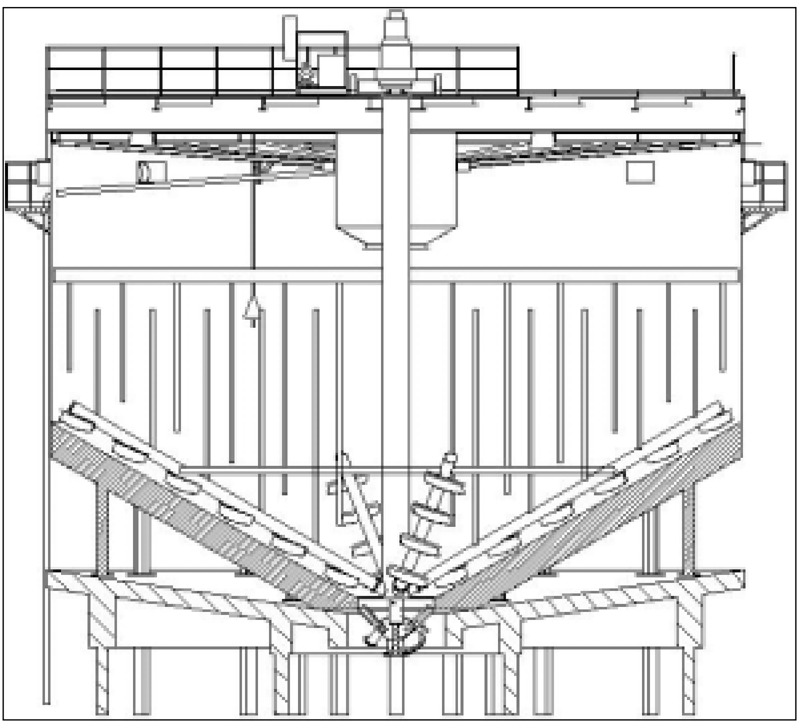

Figure 28: Bogoslovsky new Outokumpu paste thickener.