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Sizing Paste Thickeners from Pilot and Laboratory Data

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Abstract

Static cylinder testwork has long been an accepted method of sizing conventional thickeners, because of the large implicit safety margins used in scale-up. With the advent of high rate thickeners, dynamic bench-scale test rigs were introduced to provide a more accurate means of selecting thickener size and design parameters, including feed concentration, flocculant dosage and underflow density. For paste thickeners, deep-tube type laboratory-scale and pilot rigs have been developed to allow bed depths approaching the full-scale to be tested, and these have been used successfully to scale up to plant scale. However, these tests tend to consume large amounts of sample and are time consuming to carry out, hence attempts have been made to develop useful correlations, including solids residence time and the related parameter unit mud volume, to allow scale-up from tests of limited bed depth.

This paper describes work carried out by Outotec to investigate these relationships and address their validity or otherwise. The conclusion reached is that solids residence time is not reliable for scale-up and will often lead to undersizing of paste thickeners. An alternative methodology, using a variant of a filtration pressure cell as the testing device, is currently under development, and progress in this direction is described.

1 Introduction

Thickening slurries to the maximum possible density (paste) is becoming increasingly common.

Applications such as autoclave feed thickeners, paste backfill, some counter current washing (CCD) circuits and maximising water recovery from tailings 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 three metres or more. As the compression zone gets deeper, the underflow density for a given flux rate 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.

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

One of the challenges on paste thickening applications, therefore, 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 (1954) 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.

When considering paste testwork, the additional bed depth used can be a problem as a much taller test unit and a larger sample is required. It is generally not practical to operate a test rig of 6 m bed depth or more, requiring feed sample volumes of in excess of 1000 L, in a laboratory. This means a pilot-scale campaign on an operating site is generally necessary – not possible at all for “greenfield” projects, and even for “brownfield” projects, costly and time-consuming.

3 Solids residence time

The idea of using “solids residence time” in a paste thickener as a basis for scale-up is attractive for several reasons:

- We know that time in a settling bed is a factor in densification.
- Residence time is a useful parameter in many chemical and physical processes. It is a relatively easy parameter to measure or calculate.
- In the case of paste thickener scale-up, it potentially overcomes the need for tall test units and large samples.

The proposition for paste thickener scale-up is as follows:

- Define solids residence time as the time that the solids spend in the thickener, from the time that they enter the settling bed at the top, until exit at the underflow off-take.
- Operate a laboratory or pilot-scale thickener of normal depth at a relatively low solids flux, and measure the underflow density achieved at a convenient nominated bed depth.
- Calculate the nominal solids residence time in the bed to achieve the target density.
- Scale up to higher solids flux rates and greater bed depths by maintaining a fixed solids residence time – assume that the target density will be achieved providing residence time is maintained.

For example, a pilot-scale test carried out at a flux rate of 0.3 t/m²h and a bed depth of 3.0 m results in an underflow density of 65% w/w for a given application.

Nominal residence time is calculated at 11.05 hours for the solids. For method of calculation for nominal residence time, see Appendix.

Hence, by maintaining a residence time of 11.05 hours for an increased bed depth of say 8 m, a solids flux of 0.8 t/m²h can be assumed to achieve the required underflow density of 65% w/w solids.

This is a simple concept, easy to apply and potentially very useful for paste thickener scale-up.

But – does it work?

4 Outotec test campaigns

In all, three campaigns of laboratory and pilot-scale testwork were carried out by Outotec to investigate whether solids residence time (or a directly related variable, “unit mud volume”) can be used to predict performance on large-scale, deep bed thickeners.

The laboratory-scale unit was a “deep bed” style rig with a diameter of 190 mm and a total depth of 4 m, allowing a bed depth of up to 3.0 m to be run. The pilot-scale unit was a 1.0 m diameter unit with a total depth of 10 m, allowing a bed depth of up to 7.5 m. Both units were fitted with high efficiency feedwells, and the rake mechanisms were fitted with full depth dewatering pickets.

It should be noted that on all of these test campaigns, great care was taken to ensure that the settling condition of the solids bed was only affected by the bed depth and solids flux. Other variables which could have an influence, e.g. flocculant type and dosage, rotating picket speed and configuration etc. were carefully maintained across the comparative tests.

The test campaigns carried out were as follows:

- A nickel laterite feed material, tested in the laboratory at bed depths of 0.21-2.50 m and flux rates of 0.83–2.50 t/m^{2}h.
- A copper tailing material, which was tested in the laboratory at bed depths of 1-3 m, and flux rates of 0.43–1.26 t/m^{2}h.
- A gold tailings material, tested on a gold plant site, at bed depths of 3-7 m, and flux rates of 0.44–0.97 t/m^{2}h.

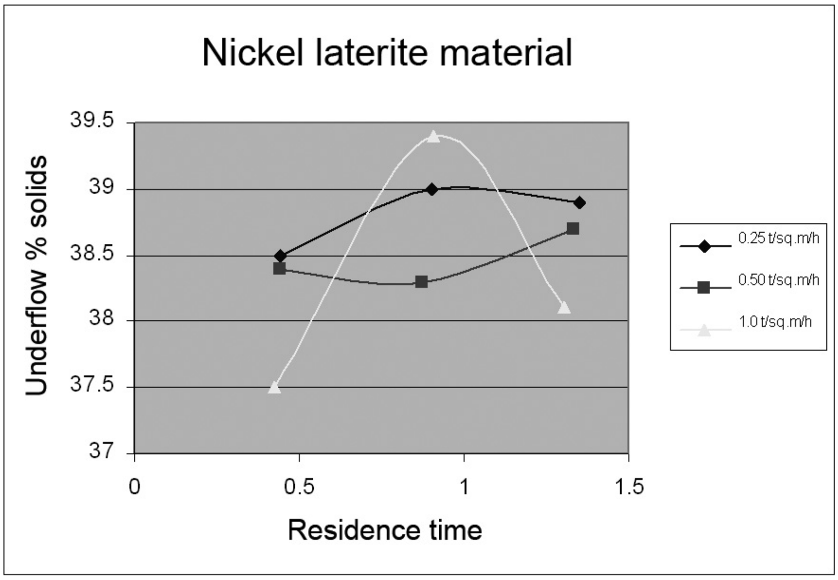

Figure 1 Nickel laterite

The results of the data on the Nickel Laterite feed were anomalous, see Figure 1, because of the crossover of the high and lower flux rate curves. If the middle point on the 1.0 t/m².h curve is ignored, however, the data suggest that the three data sets lie along distinctly different curves. Further work was clearly indicated.

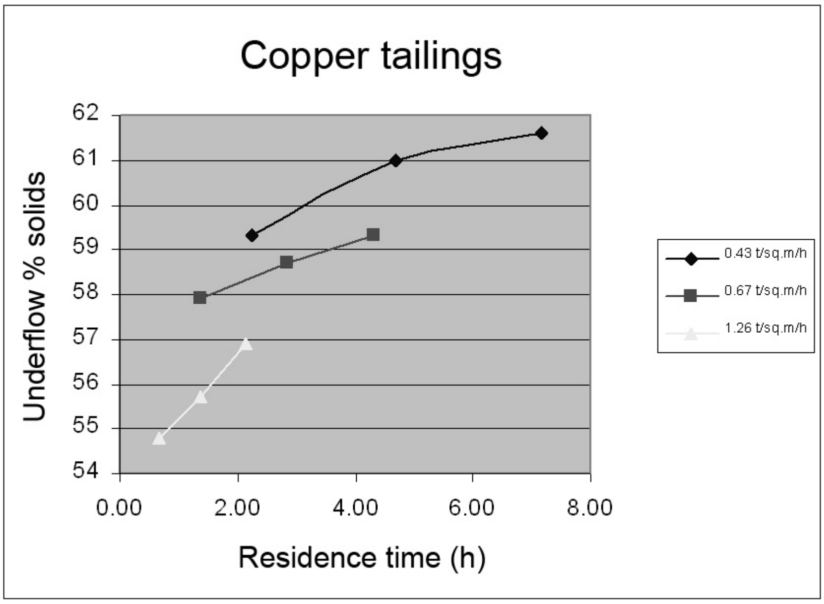

Figure 2 Copper tailings

The results of the copper tailings tests, over a bed depth range of one to three metres, was more consistent in showing the correlation between solids residence time and underflow density, see Figure 2. Again in this case, even allowing some experimental error, it did not appear that the density at higher flux rates could be viewed as lying on the same curve as at lower flux rates.

Comparing the results at a residence time of 2 hours for example, it is clear that a significantly higher density was obtained at the lower flux rate of 0.43 t/m².h than at the higher rates of 0.67 and 1.26 t/m².h respectively.

In order to obtain information on these relationships on another material, at a larger range of bed depths, a third campaign was carried out, on a pilot-scale thickener with an available bed depth of 7.5 m, on a gold flotation tailings material. Because this work was done on a plant site, continuous feed was available over long time periods – consequently it was possible to run the tests for long periods at true “steady state” conditions and hence minimise any anomalies in the resulting data. The particle size range of this material was quite consistent over the test period, with typical cumulative data as follows:

- 80% passing 100 µm.
- 50% passing 40 µm.
- 25% passing 10 µm.

The specific gravity of the solids was 2.65 t/m^3, and typical feed density to the pilot unit was 30% w/w solids.

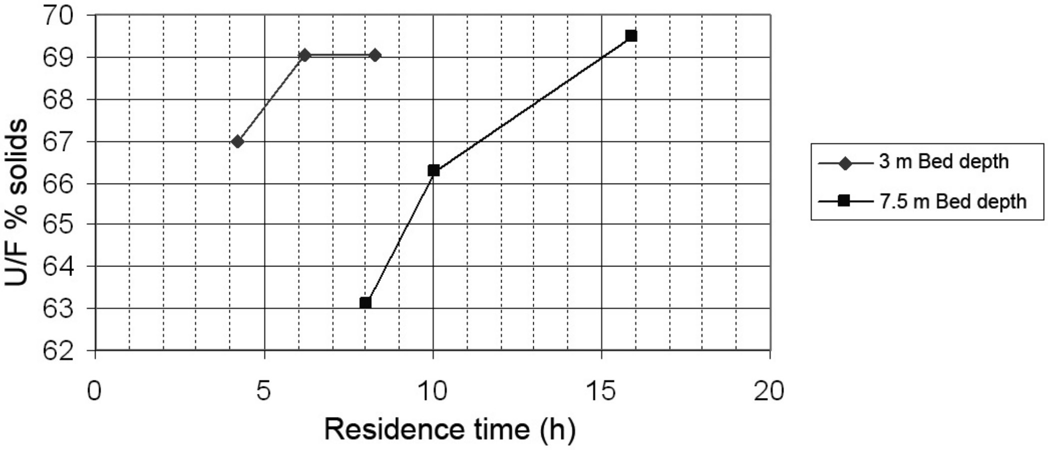

Figure 3 Gold tailings

In this case (Figure 3), the underflow density has again been plotted against nominal residence time, but with the parameter being bed depth instead of solids flux as in the previous plots. The outcome, however, is similar and in this case quite conclusive: it is not possible to predict thickener underflow density from solids residence time without having additional data on the behaviour of the material at high bed depths and flux rates.

For example from Figure 3, the density achieved at a residence time of 8.3 hours and a bed depth of 3 m is 69%. The solids flux at this bed depth was 0.44 t/m².h. If we were to use residence time to extrapolate to a higher bed depth, we would conclude that for a 7.5 m bed depth, a solids flux of 1.10 t/m².h can be achieved, with an equivalent density of 69%. The actual situation as per Figure 3 is that at a bed depth of 7.5 m and equivalent residence time (actual solids flux 0.97 t/m².h), the density obtained was only 63%. In fact, to achieve the targeted density of 69%, a residence time of 15.8 hours was required, with a solids flux of only 0.58 t/m².h.

Based on these three test campaigns, we have concluded that the use of solids residence time to predict paste thickener performance at increased bed depths is not reliable, and worse, would lead to significant undersizing of such units for production applications.

Why is this the case?

5 Bed permeability

In fact, the conclusion is not that surprising, when the nature of the thickening process is taken into account.

As the flocculated solids settle, they reach a state in which the flocs are in contact with one another and begin to exert a compressive force on one another. With increasing bed depth (or compression zone depth), the compressive force increases. If this force exceeds the compressive yield stress of the settling flocs, they will tend to release liquid and densification occurs. However, as liquid is released it percolates upwards through the settling flocs, hence creating a resistance to the compression effect of the bed. The higher the solids settling rate (or “solids flux”), the greater the upward flow of liquid and hence resistance to the compressive forces – in fact, a flux is eventually reached at which increased bed depth does not result in further thickening. This is described as “Permeability Limited Operation” by Scales and Usher (2003) who state that “For moderate to high solids fluxes, >0.1 t/m^{2}h (in this example) thickener operation is described as permeability limited. This implies that the rate at which solids are passed through the vessel is so fast that no transmission of compressive forces is achieved in the suspension bed. The limiting factor is the rate at which the liquid is able to escape from the solids network, which is dictated expressly by permeability.”

Although in the cases tested in the current investigation, they did not appear to reach the permeability limit, since increasing bed depth generally produced density improvements, nevertheless the flux was in all cases a determining factor in densification, so that it was not possible to predict an underflow density by extrapolating from a low flux to a higher one by simply using solids residence time as predictor.

6 Conclusions

Our conclusion from this work was therefore that the use of solids residence time to calculate the diameter and height of paste thickeners is not reliable, and leads to under-sizing of thickeners.

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.

7 Future actions based on conclusions

In the case of “Greenfield” projects it is very unusual to have access to enough sample for meaningful paste thickener testwork with very deep beds, therefore a small-scale laboratory method needs to be developed.

A laboratory method is being developed using a pressure cell to simulate the effect of increasing bed depths by increasing static pressure on a small sample of thickener feed, and measuring permeability function and compressive yield stress as pressure increases. These values can then be inserted into a mathematical model to allow the dynamic effects in a settling bed to be taken into account.

The pressure cell method, once validated, promises to provide a reliable solution to the problem of paste thickener scale-up based on measurements taken with small samples under the actual hydrodynamic environment. This will avoid methods based on extrapolation such as residence time and mud volume which are of limited use and have a tendency to underestimate the thickener area required for paste applications.

Reference

Scales, P. and Usher, S. (2003) The Thickening Process (Compression). International Seminar on Paste and Thickened Tailings, Melbourne, Australia, March, 2003.

Talmage, W.P. and Fitch, E.B. (1954) Determining Thickener Units Areas, Industrial and Engineering Chemistry, Vol 47, No 1, pp 38-41.

Appendix

Method of calculating nominal solids residence time:

Let Underflow density = ρ (t/m³)

Underflow solids concentration = x (% w/w)

Bed depth = H (m)

Solids flux = G (t/m².h)

Bed volume = V (m³)

Thickener cross-sect. area = A (m²)

Then we calculate a nominal solids mass W(t) and hence a nominal retention time θ(h) as follows:

$$V = HA \tag{1}$$

and:

$$W = V\rho\, x = H A \rho\, x \tag{2}$$

Hence:

$$\theta = W/A/G \tag{3}$$

$$\theta = HA\rho x/A/G \tag{4}$$

$$\theta = H\rho x/G \tag{5}$$