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RadFlow™ - the next generation feedwell

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Abstract

Metallurgical thickeners have evolved over the past century in large technological leaps rather than through a slow and steady progression. The first of these technological leaps was the introduction of polymer flocculants in the 1950s which transformed large diameter conventional thickeners (with flux rates of 1–2 t/m^2/day and a rise rate of 1 m/h) into smaller diameter high rate thickeners (with flux rates of 2–5 t/m^2/day and a rise rate of 2–4 m/h) (Paterson & Cooke, 2010). The next leap was the development of more efficient closed feedwells in the 1980s which mixed the flocculant and feed more efficiently and distributed the feed into the thickener body more evenly. Lastly, was the development approximately 20 years ago, of so-called 'auto-diluting' systems in feedwells, which allowed feed dilution to take place internally (Triglavcanin, undated).

There is still much room for improvement in thickener design and it is theoretically possible to design smaller, more stable thickeners operating at higher flux rates. In qualifying this statement, let us first consider how thickeners are sized – flocc settling rates are accurately determined with jar tests or dynamic desktop thickeners and multiplied with a safety factor of two or more to give a practical design rise rate. However, logic tells us that a rise rate, marginally smaller than the settling rate, will allow for all floccs to settle out of solution. So, where does this large safety factor stem from?

This safety factor is the result of adverse flow effects within the thickener body which arise when changing from low aspect ratio desktop thickeners to high aspect ratio industrial thickeners.

By running a myriad of experiments on a scale model thickener, adverse effects associated with standard industrial feedwells were determined. These adverse flow effects include tangential swirl, radial recirculation and flow asymmetry. To counter these effects, a series of feedwell models were constructed and tested in the scale model thickener; options included shelves, baffles and vanes in varying configurations and geometries. Ultimately, the RadFlow™ feedwell evolved which best countered these adverse effects so that flocculated feed is evenly and gently introduced to flow into the thickener body.

1 Introduction

Thickeners are designed on the assumption that a uniform horizontal velocity flows from the feed pipe into the feedwell, which is converted to a uniform downward velocity in the feedwell and is finally, miraculously transformed into a uniform rise rate within the thickener body as shown in Figure 1. Assuming these uniform flows is implicit with assuming fluid energy minimisation throughout the thickener.

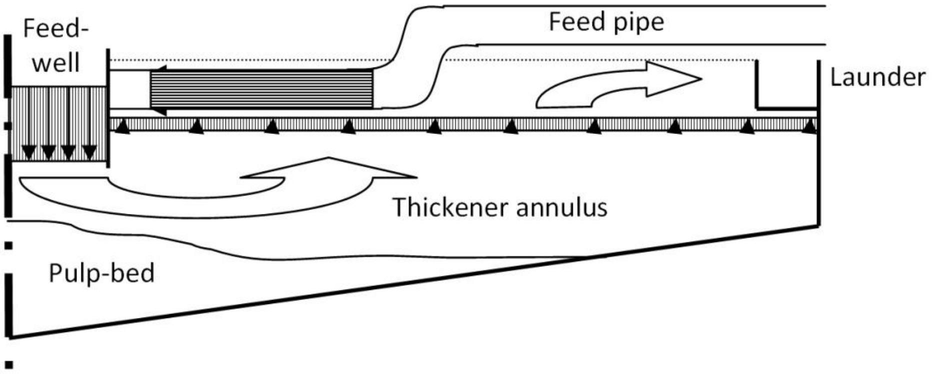


Figure 1 Cross-section of assumed velocity profiles through thickener

The only problem is that fluids do not work this way; there are no flow mechanisms to establish or enforce these flow regimes. However, large rise rates, the magnitudes of which tend towards flocc settling rates, are achievable in mini bench top thickeners. The disparity in rise rates between bench top mini thickeners and industrial thickeners is essentially due to the differing aspect ratios. Thickeners generally have high aspect ratios (short and squat), while bench top mini thickeners have low aspect ratios (tall and skinny) and therefore the flow tends towards a uniform pipe flow.

Furthermore, industrial standard feedwells dissipate only a small fraction of the feed's incoming energy, the excess of which later wreaks havoc in the thickener body in the form of swirling, short-circuiting and pulp-bed scouring; manifestations of a non-optimal thickener operation. In order to subdue these adverse effects, a thickener is generally oversized by a factor of two or more, i.e. as a rule of thumb the rise rate is half or less than that of the flocc settling rate. The key to a more efficient thickener lies in dissipating this kinetic energy and introducing the feed more evenly into the thickener body which is done with a more efficient feedwell. Moreover, efficient energy dissipation within the feedwell is congruent with effective flocculant and feed mixing, and supernatant mixing for diluting feedwells (Arbuthnot, 2008).

As many companies shift towards re-examining the feedwell for more efficient thickener operation, a lingering and false perception that limits the fundamental understanding of a thickener's performance is that the feedwell forms a distinct zone from the thickener body. For example, feedwells are designed on the assumption that all flocculation occurs only within the feedwell; while flocculation actually occurs both inside and outside of the feedwell. Effectively, this is saying that thickener bodies are designed separately from feedwells. In contrast, Roymec has designed the RadFlow feedwell by considering the interaction of the flow from the feedwell into the thickener body with dramatically improved results.

2 Idealised flow analysis

Thickeners have traditionally been sized by considering two parameters, namely the average flocc settling rate x, and the plug-flow rise rate $\bar{v_z}$ in the thickener body (Essak, 2010, written comm.). Theoretically, in order to achieve flocc settling:

$$\bar{v_z} < x. \tag{1}$$

A schematic of this plug-flow rise rate is given on the left hand side of Figure 2. It is noted that $\bar{v_z}$ is invariant with elevation.

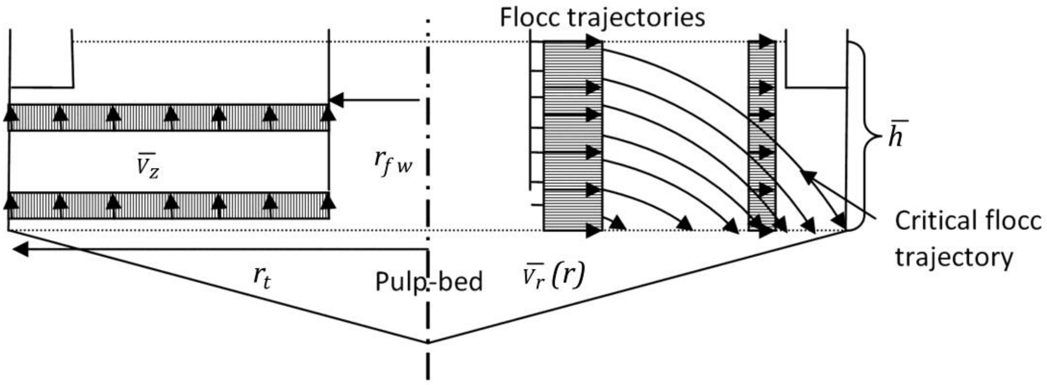


Figure 2 Assumed axial plug-flow velocity in the thickener annulus

By modifying Equation (1) it is easy to show that in order for settling to occur, the area of the thickener body must exceed:

$$A_A = \pi\left(r_t^2 - r_{fw}^2\right) > \frac{Q}{x}, \tag{2}$$

where r_t and r_{fw} respectively denote the radius of the thickener and feedwell and Q is the flow rate.

An axial plug flow is a highly idealised scenario and in practice is impossible to achieve and is thus referred to as an *asymptotic* limit. For the sake of argument, let us now consider another asymptotic limit: a radial plug-flow $\bar{v}_r$, seen on the right hand side of Figure 2. For a radial plug flow, the radial velocity is a function of the radius and floccs do not fall vertically to the pulp-bed but follow a trajectory, again seen on the right hand side of Figure 2.

For the radial plug flow, a uniform thickener depth $\bar{h}$ is approximated for the sake of simplifying calculations; this may be a relatively accurate assumption due to the formation of a pulp-bed. The radial plug-flow is modelled as a source flow, and by equating the time required for a flocc to move from the feedwell to the outer radius (launder) with the time taken for it to sink to the pulp-bed, it can be shown that this critical flocc trajectory requires a thickener area given by Equation (2), i.e. the same as for an axial plug flow. Hence, both asymptotic flow regimes require the same thickener area.

It is also noted from Equation (2) for both radial and axial plug flow asymptotic limits, flocc settling is proportional only to the thickener area (or radius) and not depth. This is reflected in practical thickener design where depth is not a critical design parameter and is usually only considered for underflow density.

However, let us now consider distribution of floccs on the thickener floor or pulp-bed. Theoretically, an axial plug-flow distributes the floccs evenly across the entire floor area, as shown by the dashed line in Figure 3, in which Q_s is the normalised solids settling rate. This can be thought of as the depth profile of a pulp-bed over a certain period, if neither raked nor subjected to underflow extraction.

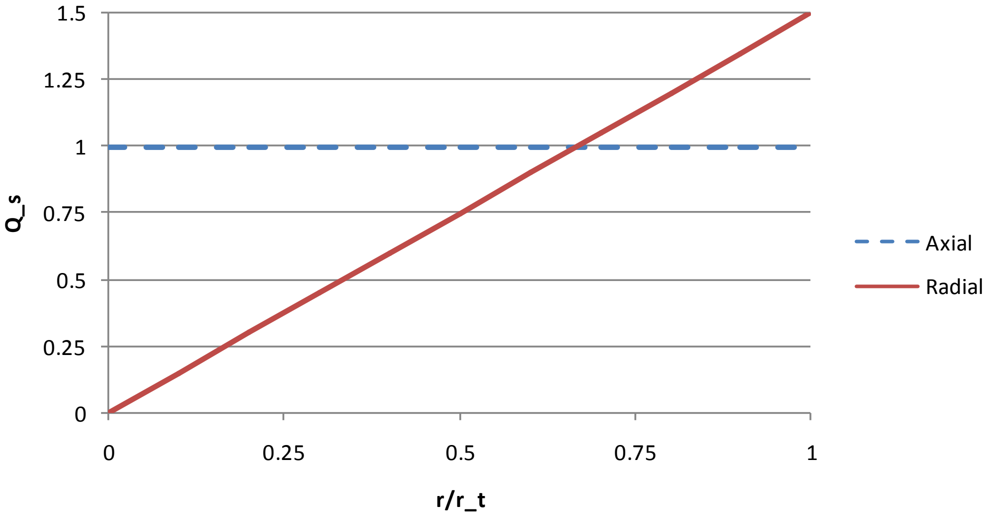


Figure 3 Flocc distribution rates on thickener floor for an assumed axial and radial plug-flow

On the other hand, a radial plug-flow, emanating from the feedwell wall (uniformly distributed across the feedwell height), will yield a radially increasing solids settling rate following the relationship:

$$Q_s \propto \frac{r}{r_t}. \tag{3}$$

This relationship is shown as the solid line in Figure 3. On this basis, it would appear that the flocc distribution arising from an axial plug-flow is more advantageous than that arising from a radial plug-flow (Figure 2) because less raking would be required to draw pulp back to the centre.

More importantly though, for an axial plug-flow, if $A_A < Q/x$ (Equation (2) with a switched sign), settling cannot occur. However, for a radial plug-flow if $A_A < Q/x$, settling will still occur within the thickener with only a fraction of the floccs exceeding the theoretical radial limit (thickener radius), i.e. flowing into the launder. This can be thought of as truncating the right hand end of the radial plug flow settling curve in Figure 3 (the magnitude of truncation would be proportional to the magnitude with which the rise rate exceeds the flocc settling rate).

It is therefore concluded that a *radial plug-flow regime* yields a flocc settling regime that is *more stable* than an axial plug-flow system. Therefore, the flow within a *thickener body* should as far as possible *follow a radial plug-flow* regime to increase the thickener's operational stability. The RadFlow feedwell is based on this analysis in that it *best promotes a radial plug-flow*.

3 Scale model methodology

The biggest advances made by Roymec in understanding thickener shortcomings and consequently in developing the revolutionary RadFlow feedwell were made in a 1 mØ Perspex scale model thickener, shown in Figure 4(a). This model was built to scale off the plans of an operating 21 mØ Roymec thickener.


(a) (b)

Figure 4 (a) Scale model thickener using only water, (b) Scale model retrofitted with rake arms and flocc emulator

This scale model thickener is fed with a header tank, shown in the back left of Figure 4(a) and has a circumferential launder. Water is recirculated through the scale model with a pump at a flow rate of 0.5 l/s, yielding a rise rate of 2.3 m/h.

Various feedwells were tested as indicated earlier but only three versions are reported on herein, namely the open, closed and ultimately the RadFlow feedwell, see Figures 5(a), (b) and (c) respectively. The RadFlow feedwell essentially consists of two distinct zones: a feedwell zone and a flow shaping zone. The feedwell zone is essentially a tangential entry feedwell bounded between an upper and lower shelf. The flow shaping zone comprises multiple blades, mounted to the underside of the lower shelf with a predominantly vertical orientation.

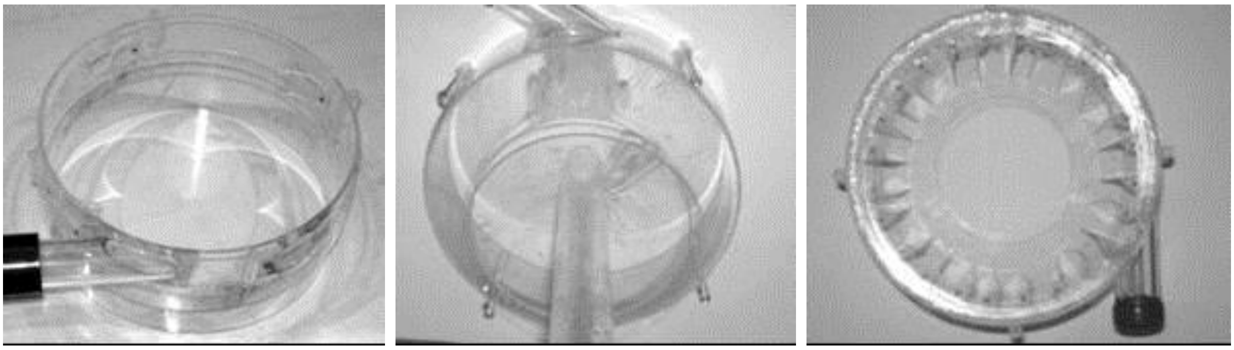

(a) (b) (c)

Figure 5 (a) Open feedwell, (b) closed feedwell and (c) RadFlow feedwell

Before proceeding with the experimental results, it must be noted that operating the scale model thickener with only water is equivalent to operating an industrial thickener without an established pulp-bed or hindered settling zone. Although this view may be limited in that factors such as hindered settling zone feed injection are not considered, it is believed that this technique establishes the fundamental fluid dynamics within a thickener. Justifying this statement is the observation that the fluid dynamics remained largely invariant when the scale thickener was retrofitted with rotating rake arms and in exchange resin was used as a flocc and pulp-bed emulator, compare Figure 4(a) with (b).

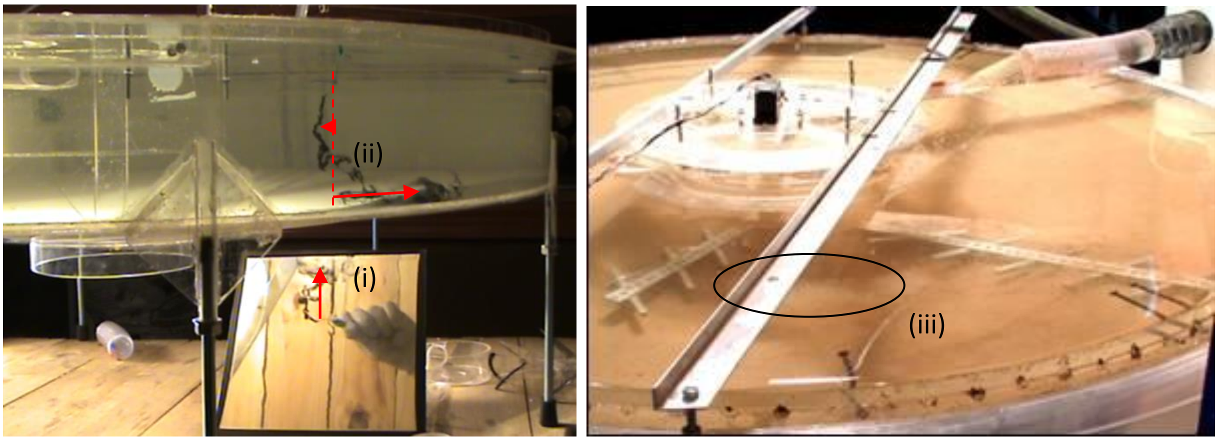
4 Results

Initially, flow patterns were established in the scale model with dye tracer tests; see Figure 6(a). Three major adverse flow conditions were observed when testing an open feedwell, namely tangential swirl [Figure 6(a)(i) and Figure 7(a)], radial recirculation [Figure 6(a)(ii) and Figure 7(b)] and flow asymmetry [Figure 6(b)(iii) and Figure 7(c)].

Tangential swirl can be seen on the top of almost all operational thickeners, see Figure 7(a). The disadvantage of this flow regime is that if the tangential swirl is too great, then floccs may be scoured off the pulp-bed back into solution. Furthermore, due to centripetal forces, floccs are flung further radially outwards in the thickener than for a non-rotating fluid body; rake arms then need to do more work in drawing the pulp back to the centre.

Unlike tangential swirl, radial recirculation and flow asymmetry cannot be seen on the surface of an operational thickener. However, similar to tangential swirl, radial recirculation also transports floccs to the outer extremities of the thickener at which point some floccs settle and others are washed upwards along the thickener wall and short circuit directly into the launder, see Figure 7(b). Moreover, again like tangential swirl, high shear stresses on the pulp-bed can scour already settled floccs back into the solution which may then also short-circuit.

Flow asymmetry is the variation in velocities, or energy, at similar radii around the thickener body and is expressed in the form of radial recirculation magnitude. For example, when testing the open feedwell it was observed that there was far greater radial recirculation in the thickener body opposite the feed pipe entry point than adjacent to it. When testing the scale model with an emulated pulp-bed, Figure 4(b), flow asymmetry was observed as flocc scouring and short circuiting in the high energy zone and a relatively dead zone at the low energy zone, see Figure 6(b) (iii) and Figure 7(c).



(a) (b)

Figure 6 (a) Dye tracer test with tracer drawn vertically upwards showing (i) tangential swirl (45° mirror) and (ii) radial recirculation (front view); and (b) emulated flocc and pulp-bed test showing (iii) flow asymmetry: scoured patch exposing floor opposite to the feed pipe entry

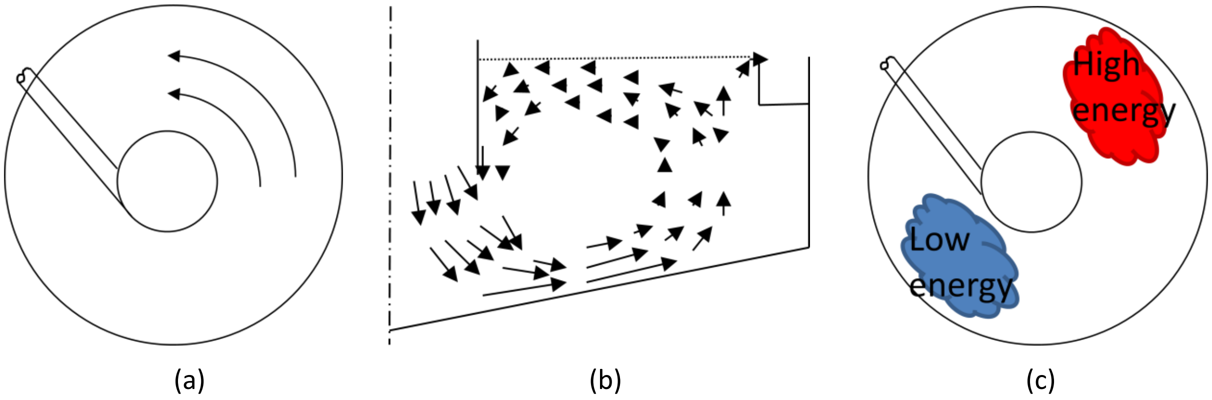


Figure 7 Adverse flow conditions of an open feedwell include: (a) Tangential swirl, (b) Radial recirculation and (c) Flow asymmetry

When testing the closed feedwell, it was observed that the tangential swirl was marginally reduced compared to the open feedwell. It was also found that the energy asymmetry was eliminated, i.e. there was a uniform radial recirculation around the thickener.

Before the scale model was retrofitted with a pulp-bed emulator (Figure 4(b)), coffee grounds were introduced into the feed to examine settling patterns on the scale model floor, see Figure 8.

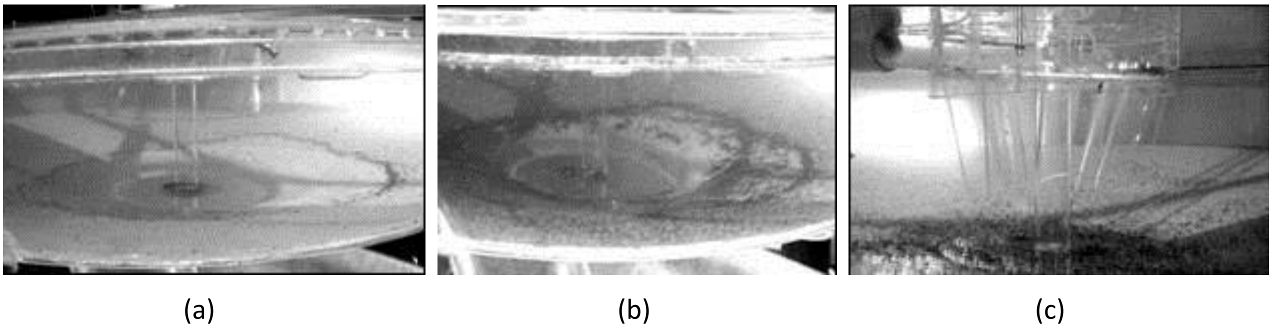


Figure 8 Settling patterns of coffee grounds on scale thickener floor using (a) open feedwell, (b) closed feedwell and (c) RadFlow feedwell

Figure 8(a) shows that the open feedwell inhibits settling directly below the feedwell. Furthermore, the settling pattern is asymmetrical with floccs settling furthest away from a point opposite the feed pipe entry. This settling pattern is consistent with the observed flow asymmetry established by the open feedwell, Figure 7(c). Figure 7(b) also shows that the closed feedwell also inhibits settling directly below the feedwell, but to a lesser extent than that of the open feedwell, i.e. settles closer to the centre. Moreover, the settling is more symmetrical and is therefore consistent with the observation that the flow asymmetry was reduced by this feedwell design.

Finally, Figure 8(c) shows that the RadFlow feedwell does not inhibit settling with most of the floccs settling almost directly below the feedwell with no associated asymmetry. This settling pattern illustrates the best possible scenario for an industrial thickener in which the rake arms need do little work to draw the pulp to the centre. This settling pattern is suggestive that the flux rate of the thickener can be dramatically increased using the RadFlow feedwell.

Additional benefits of the RadFlow feedwell seen during testing include: i) Intense mixing in the feedwell zone, which allows for intense flocculant/feed contact and therefore a reduction in flocculant consumption and ii) An auto-dilution effect, in which eddies formed on the outer surface of each blade draws supernatant surrounding the flow shaper back inwards.

5 Conclusion

Roymec has identified that the disparity between flocc settling rates and practically achievable rise rates in operational thickener is essentially due to feedwell design inefficiencies. Theoretically, thickeners can be built with a rise rate marginally less than the average flocc settling rate. However, in practice, thickener rise rates are generally less than a half the average flocc settling rate. Hence, it is feasible that with a more efficient feedwell design, thickeners could operate close to the average flocc settling rate. This is equivalent to saying that a traditional (current) thickener could be replaced with a thickener of almost half the area when utilising the RadFlow feedwell.

Through intensive scale model experimentation, Roymec has successfully identified the limitations that standard industrial feedwells place on thickeners. With this deepened fundamental understanding of thickener operation, Roymec has reengineered traditional feedwell systems yielding the highly efficient RadFlow feedwell.

6 Future work

The RadFlow feedwell has been patented based on the current research.

Spurred on by promising results demonstrated by the RadFlow feedwell in scale model experiments, Roymec is currently testing the RadFlow feedwell in a Computational Fluid Dynamics (CFD) package Flo.EFD™ and is concurrently running field trials with the RadFlow feedwell in a 2.4 mØ pilot plant.

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