Improving Thickener Performance Using the Radflow™ Feedwell: From CFD Modelling to Commercial Implementation

Alex Krassnokutksi

Krassno Consulting, Johannesburg South Africa

Corresponding author: alex@krassno.co.za

Ezulwini's counter-current decantation (CCD) thickener circuit, commissioned in 2009–10, consisted of six 21 m diameter thickeners fitted with conventional open feedwells with auto-dilution slots and deflector plates. From the onset, the circuit experienced several operational difficulties including, ineffective dilution, an unsteady rake drive (the mechanism could be seen rocking), high flocculant consumption, excessive solids in overflow, and frequent sliming. In 2013, a decision was made to retrofit three of the six thickener feedwells with Radflow feedwells and forced dilution (ETAQ) pumps. Subsequent to this upgrade, the retrofitted thickeners have shown a marked improvement in performance, including the overflow clarity is well within specification, the rake drives have stopped rocking (due to the axi-symmetric distribution in the thickener body); flocculant dosage requirements have been reduced by more than 30%, and, most importantly, operators have noted a marked increase in operational stability of these retrofitted thickeners, resulting in less down time and increased production.

This paper uses Computational Fluid Dynamics (CFD) to examine the difference in performance of the open feedwell (with deflector plates) against the Radflow (in addition to the closed feedwell, which was also considered as a retrofit option). This comparative analysis shows that the Radflow feedwell substantially outperforms its standard industrial counterparts. The positive site feedback of the retrofitted feedwells supports the CFD methodology used to analyse the feedwell performance.

INTRODUCTION

Feedwell Designs

There are myriad feedwell designs in the thickener market but, for the sake of brevity, we will limit ourselves to the most prevalent, namely, open (with a deflector plate) and closed feedwells, as shown in Figures 1(a) and (b), respectively. These two feedwells are compared against Roytec's proprietary Radflow™ feedwell, as shown Figure 1 (c).

Krassnokutski (2012) previously experimented with scale model thickeners using water as a working fluid and has showed that (under the assumption of a homogeneous working fluid) standard industrial feedwells are subject to a host of adverse flow conditions. More specifically, the adverse flow effects associated with an open feedwell include: tangential swirl, radial recirculation and flow asymmetry, as shown in Figure 2.

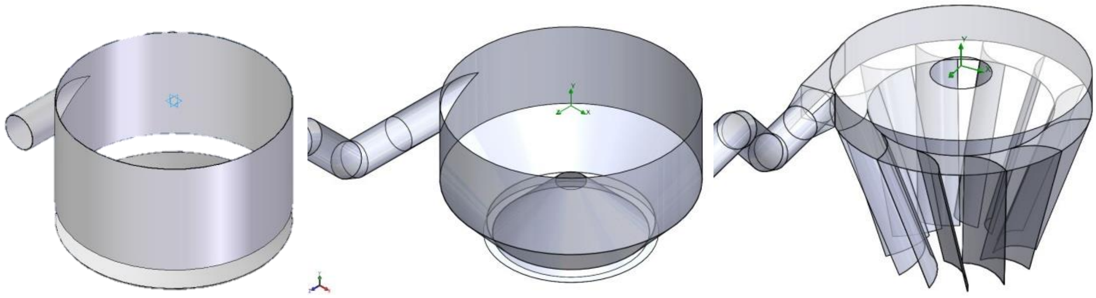

Figure 1. (a) Open feedwell (with deflector plate), (b) closed feedwell, and (c) Radflow™ feedwell.

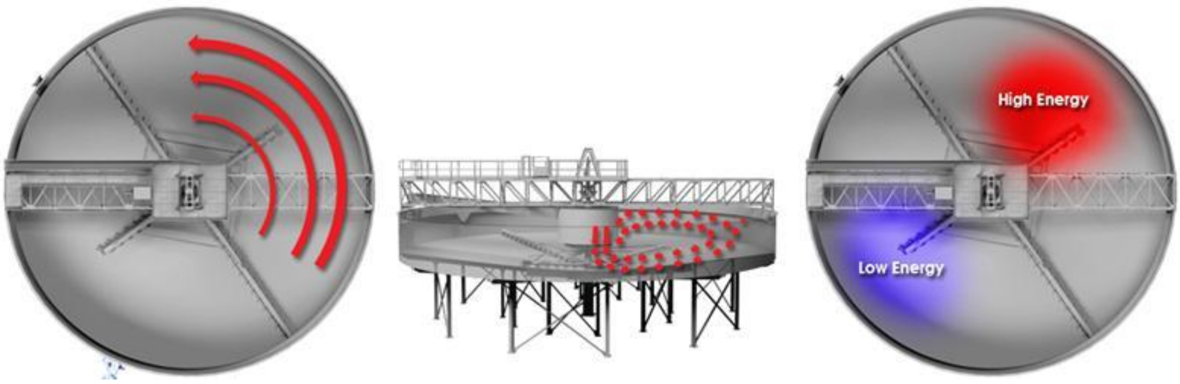

Figure 2. Adverse flow conditions of an open feedwell include (a) tangential swirl, (b) radial recirculation and (c) flow asymmetry.

The performance of a closed feedwell is better than that of an open feedwell because of negligible flow asymmetry and reduced tangential swirl and radial recirculation. This is due to the more consistent feedwell discharge velocity through an axi-symmetric discharge annulus (shown later). It is speculated that this is partly the reason that the closed feedwell became such an effective successor to the open feedwell in the 1980s.

Feed Dilution

When the feed to a thickener has a solids' concentration greater than 10% (material specific), a multitude of problems are generally encountered (Heath, 2009; Osborne, 2013), namely:

i. Inefficient mixing between the feed and the flocculant takes place. This is owing to:
   a. a greater density differential between the flocculant solution and the feed,
   b. a greater viscosity of the feed.
ii. A very slow initial solids settling rate due to the lack of discrete floc particles.
   a. These discrete floc particles can also accelerate the consolidation rate later during the densification phase of thickening.

Hence, if a thickener feed density is greater than 10% (material specific) then, if possible, the feed should be diluted down to about 5 to 7 %.

EVOLUTION OF THE EZULWINI CCD THICKENER CIRCUIT

Roytec commissioned Ezulwini's counter-current decantation (CCD) uranium thickener circuit in 2009–10. The circuit consisted of six 21 m diameter thickeners, all fitted with conventional open feedwells (with deflector plates) and with auto-dilution slots, shown in Figure 3(a).

Open Feedwell with Auto-Dilution Slots

The open feedwells (with deflector plates) were designed for a feed rate of 600 m^3/h (at a specific gravity (SG) = 1.2) and a feed to dilution ratio 1:2, i.e., a dilution stream of 1200 m^3/h. Since its commissioning, the circuit experienced several operational difficulties, including:

- Inefficient dilution;
- An unsteady rake drive (the mechanism could be seen rocking);
- Excessive solids in overflow;
- Occasional sliming of the thickeners (see Figure 3(a)).

Despite the driving head differential between the feed, it was occasionally observed on site that a stream of feed would exit through one of the of the dilution slots. This presumably happened when the pulp bed or hindered settling zone (HSZ) built up to the extent that it induced a back pressure in the feedwell. Needless to say, it was identified that the auto dilution slots did not dilute the feed-stream sufficiently.

In an attempt to fix the above problems, Roytec modified the open feedwells by enlarging the dilution slots. Additionally, the dilution slots were shielded with directional baffles so that the feed did not short circuit through these slots due to centripetal effects (see Figure 3(c)). Moreover, these baffles were designed to induce a Venturi effect, thereby drawing even more supernatant. Despite these modifications, the above problems persisted (see Figure 3(b)).

Figure 3. (a) Stalled and drained thickener with original open feedwell (with deflector plate). (b) Sliming thickener (with dilution slot modification), and (c) computer-aided design (CAD) drawing of the modified feedwell (with enlarged slots and added deflection baffles, deflector plate not shown).

Due to the number of operational difficulties experienced, Roytec then investigated the prospect of retrofitting the existing feedwells with a more efficient closed feedwell design. More importantly, it was realized that a more effective dilution system was required. Hence, the proposal of using an external dilution system was investigated.

Closed Feedwell with External Dilution

A schematic of the closed feedwell is shown in Figure 1 (b). The dilution stream would have to be collected from the overflow and pumped back into the feedwell by an external agitator/pump system which would be supplied by an external vendor. The analysis of this agitator/pump system is beyond the scope of this paper, however, it must be noted that both the feed pipe and collection launder would need to be enlarged for such a retrofit.

For the subsequent simulations, the feed pipe diameter is enlarged from a 400 NB to 600 NB pipe. It must be realised that this dilution system entails significant head losses (approximately 0.5 m) that would be incurred by needing to overcome long pipe and discharge losses, in addition to the waterfall height into the launder.

Radflow Feedwell with the ETAQ Pump

While a closed feedwell was being considered as a retrofit for Ezulwini, Roytec's NexGen thickener programme was finalizing the design of the Radflow feedwell and ETAQ pump. The Radflow feedwell and ETAQ pump were subject to an intensive computational fluid dynamics (CFD) analysis and showed superior performance compared with the closed feedwell. The Radflow design was therefore selected as the replacement feedwell for the problematic Ezulwini CCD circuit, as shown in Figure 4.

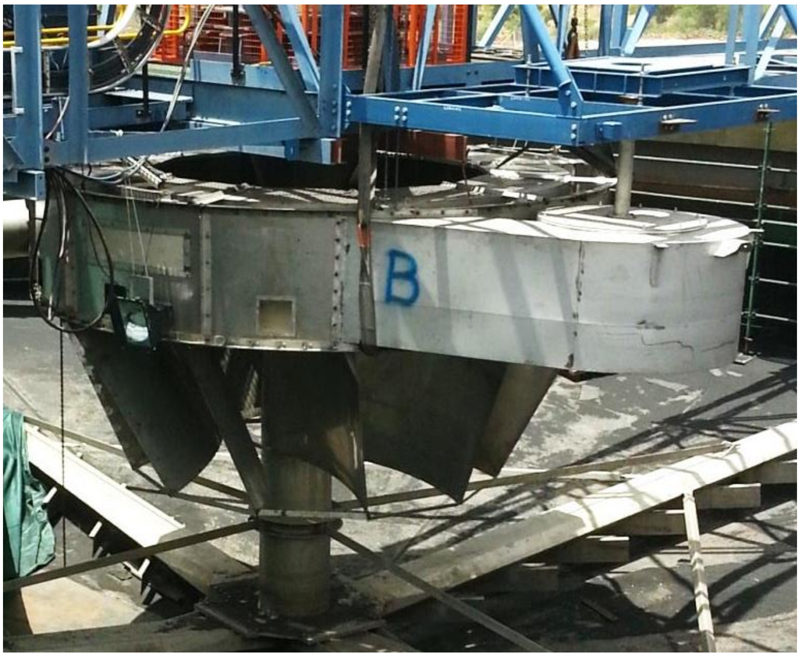

Figure 4. Radflow feedwell and ETAQ pump installed at Ezulwini.

In summary, the Ezulwini CCD uranium thickener circuit was:

- Commissioned with an open feedwell with deflector plates and auto-dilution slots.
- Intended to be retrofitted with a closed feedwell with external dilution.
- Ultimately retrofitted with the Radflow feedwell with the ETAQ pump.

Permission to publish comparative data showing the quantitative differences of the CCD thickeners using the Radflow and open feedwells (with deflector plates), i.e., thickeners seeing the same duty was not permitted. However, it can be stated that cumulative after-sales service man-hours to the originally commissioned CCD circuit exceeded 550 hours. On the other hand, after the Radflow retrofits, the after-sales service man-hours stand at a mere 8 hours (to correct for some assembly/alignment errors).

The above evolution of the feedwell design is a useful case study for a CFD analysis, as it compares the performance of the open, closed and Radflow feedwells against one another (see Figure 1). This paper discusses the development of the Radflow feedwell using CFD modelling and indicates how such significant performance gains were possible.

CFD ANALYSIS

CFD Overview

FloEFD™ is the CFD package used for this analysis. *FloEF*D is a RANS (Reynolds Averaged Navier Stokes) solver and uses the $k - \varepsilon$ turbulence model. *FloEFD* also features advanced mesh refinement which allows a coarse mesh to be refined during a simulation, thereby minimising the number of cells per simulation and optimising calculation times.

Modelling Assumptions

For all of the following CFD simulations, only water is used as a working fluid. This is a limiting approximation because, in reality, the feed rheology undergoes a "metamorphosis" (for lack of a better term) from a low viscosity, low density feed to discrete suspended solids (flocs), and then ultimately to a high viscosity, high density underflow, all whilst liberating water. The actual process of flocculation is exceedingly difficult to model, however some successes have been had by the AMIRA P266 program using a population balance model (Fawell, 2009). However, for this analysis, we will limit ourselves to a more straight-forward homogenous fluid model.

The pulp–bed interface was modelled as a horizontal lid just above the outermost tip of the rake arms, i.e., by cordoning off the conical section of the thickener. It is noted that modelling the pulp–bed/clarified zone interface as a solid–liquid interface is not an accurate approximation. However, the alternative of modelling a rheological gradient of slurry (with including density, viscosity and pseudo-plasticity) is hugely complex. Furthermore, accurate rheological data for this gradient are not readily available and this rheological gradient will vary depending on how the thickener is operated.

Possibly the biggest short-coming of the following simulations is the lack of an HSZ. An HSZ acts as a buffer (or damper) for the feed exiting the feedwell. Moreover, this HSZ can act like a so-called dynamic sponge in which flocs exiting the feedwell are assimilated by the HSZ sponge-like structure and thus adding to its matrix. However, the HSZ can also be eroded and solids can be re-suspended if the velocities exiting the feedwell are too high.

Bearing the above assumptions in mind, the subsequent CFD results can be thought of as the worst-case scenario, essentially representing a thickener at start-up without an established pulp-bed or HSZ.

CFD RESULTS AND DISCUSSION

Each simulation takes place in a 21 m diameter thickener with a 2.5 m sidewall and 7° floor slope. All feedwells are 2.5 m in diameter and both the open and Radflow feedwells have a 400 NB feed pipe to deliver a feed flow rate of 600 m^3/h. On the other hand, the closed feedwell has a 600 NB pipe to deliver a diluted feed flow rate of 1800 m^3/h (due to external dilution). The flow rate through the ETAQ pump was set to a dilution flow of 1200 m^3/h.

For the purposes of a fair comparison, the dilution stream into the open feedwell through the auto-dilution slots was also set to 1200 m^3/h. However, is likely that such flow rate would never be practically achievable by this type of dilution system. It is suspected that, in part, this is responsible for the poor performance of the open feedwell, as elaborated upon above. The above specifications are not the exact design specifications for the Ezulwini CCD circuit, but rather represent the ballpark figures for a standard CCD circuit, i.e., a 1:2 feed to dilution ratio and rise rate just exceeding 5 m/h.

Figure 5 shows the velocity contours through the thickener using the open, closed and Radflow feedwells. It is immediately apparent that the Radflow design substantially reduces the average velocity in the thickener body.

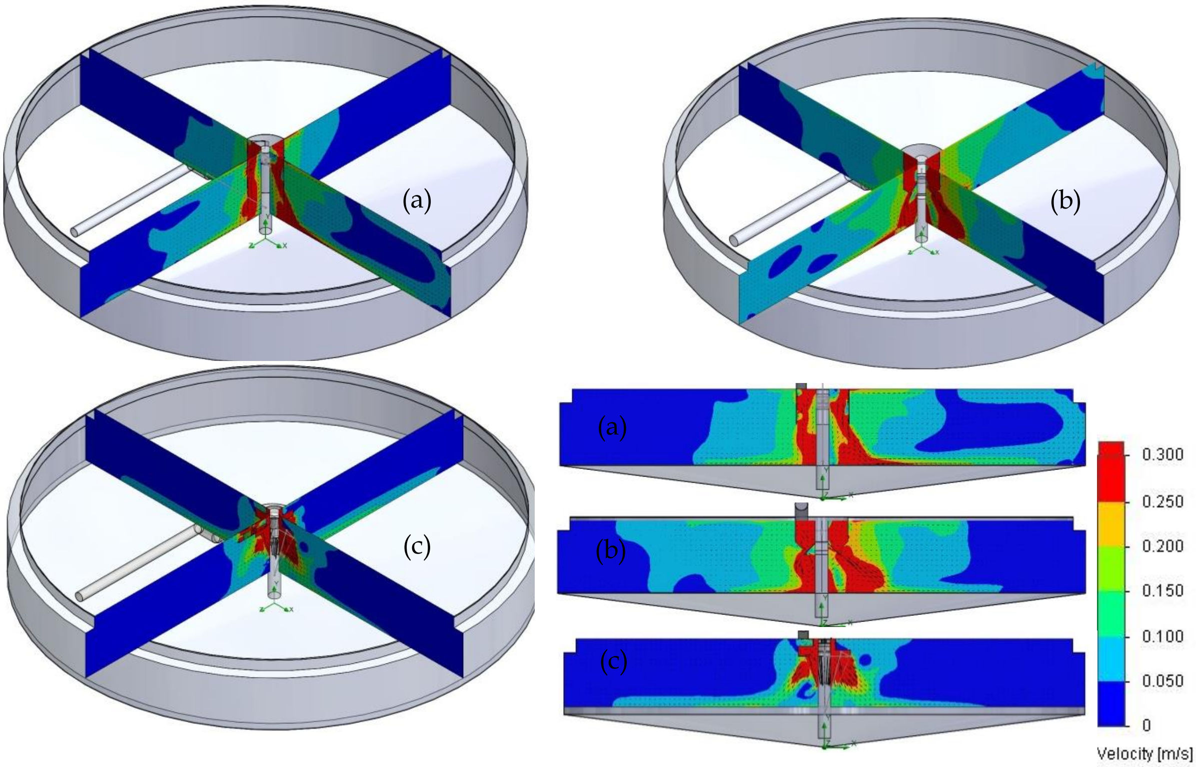

Figure 5. Velocity contours from an isometric and front-view perspective for a thickener operating with (a) an open feedwell, (b) closed feedwell and (c) the Radflow feedwell.

A more convenient and intuitive way of viewing this same information is via velocity iso-surfaces, as shown in Figure 6. It is now clear that the open feedwell induces a high velocity tail along the thickener floor, approximately 270° from the feedpipe entry, and indicates the asymmetry of the open feedwell, as shown in Figure 2 (c) and discussed in the associated text. This high velocity tail may scour the thickener floor (or HSZ/pulp bed) of already settled flocs and can even scour the thickener floor clean if the feed velocity is high enough.

Another adverse effect of this flow asymmetry is the maldistribution of solids on the thickener floor/pulp bed. This has the knock-on effect of the rake seeing alternating loads as it rotates through the pulp bed. It is suspected that this effect was responsible for the rocking of the rake drive mechanisms at Ezulwini when the thickeners were operating with open feedwells.

The closed feedwell gives a far better axi-symmetric distribution than the open feedwell, however velocities exceeding 0.15 m/s still flow along the pulp–bed interface below the feedwell. The Radflow feedwell performs best of all, with a very localised velocity cloud (0.15 m/s) surrounding the feedwell but far away from the pulp–bed interface.

Dynamic pressure can loosely be thought of as a “blowing force” and thus is the key indicator in determining whether a particle will settle, remain in suspension or even be blown back into suspension. Dynamic pressure is defined as:

$$p_{dyn} = 1/2 \rho v^2, \quad (2)$$

i.e., a v^2 relationship. Applying this relationship to Figure 6 yields Figure 7, which shows dynamic pressure iso-surfaces at 40 Pa (red), 20 Pa (green) and 10 Pa (cyan). This shows that settling will be least inhibited by the Radflow feedwell, thus minimising settling and consolidation time.

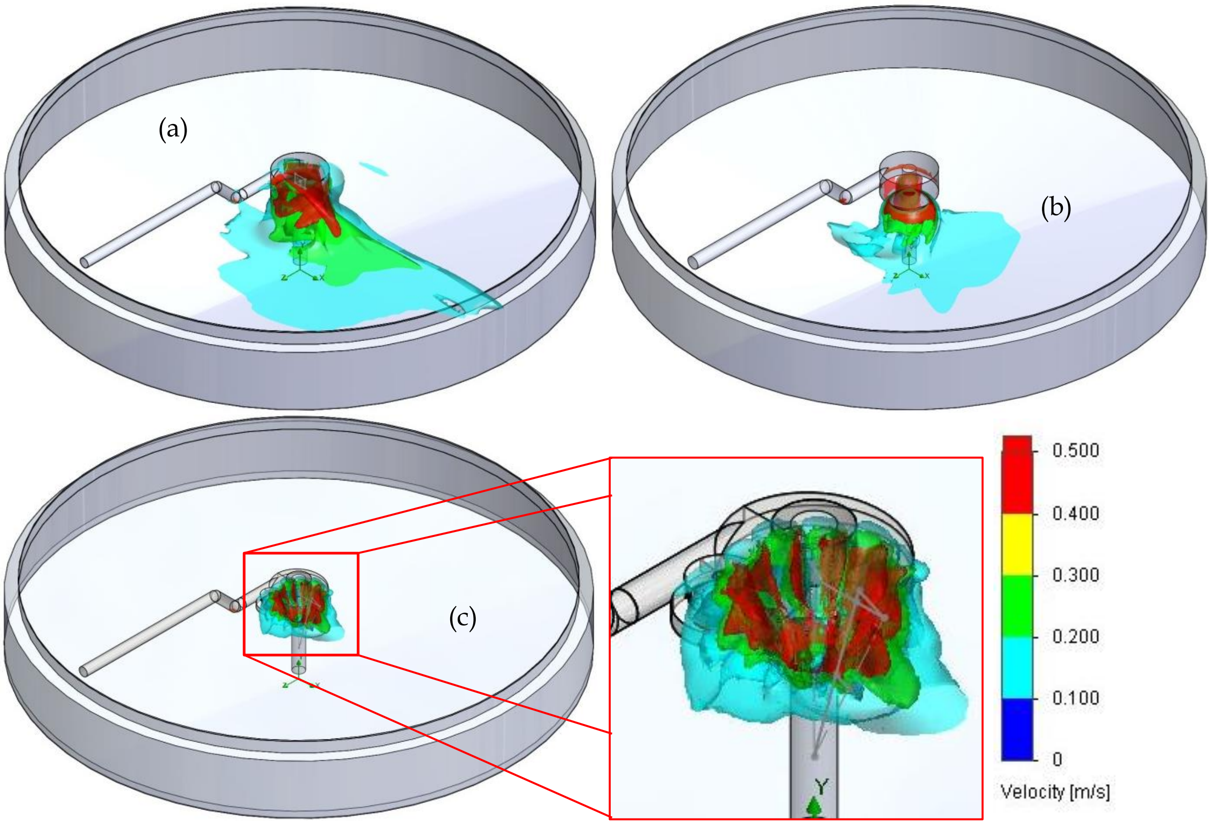

Figure 6. Velocity iso-surfaces at 0.45 m/s (red), 0.3 m/s (green) and 0.15 m/s (cyan) surrounding (a) an open feedwell,(b) closed feedwell and (c) the Radflow feedwell.

A result of the Radflow's gentler, more symmetric distribution into the thickener body is a more uniform and gentler radial recirculation. This radial recirculation forms part of the rise rate at the thickener wall, as shown in shown in Figure 2 (b) and elaborated on in the associated text. Figure 8 shows this vertical velocity across the thickener area for various feedwell designs. Vertical velocities at the thickener walls are responsible for the carry-over of fines. Hence, the lower the vertical velocities at the walls, the lower the capacity for carry-over of solids.

It can be seen that both the open and closed feedwells have localised regions of high vertical velocities at the thickener wall, both exceeding 0.1 m/s. However, the Radflow manages to restrict this localised rise rate, barely exceeding 0.025 m/s.

The final parameter to observe is the shear stress induced on the thickener floor by the various feedwell designs. This is shown in Figure 9 and shows that the open feedwell induces a large, asymmetrical area of shear that is likely to re-suspend already settled flocs. The closed feedwell performs better, but shear stress patches in excess of 0.5 Pa are still evident. On the other hand, the Radflow feedwell gently and axi-symmetrically distributes the feed in the thickener body so that the localised shear stress only just exceeds 0.1 Pa.

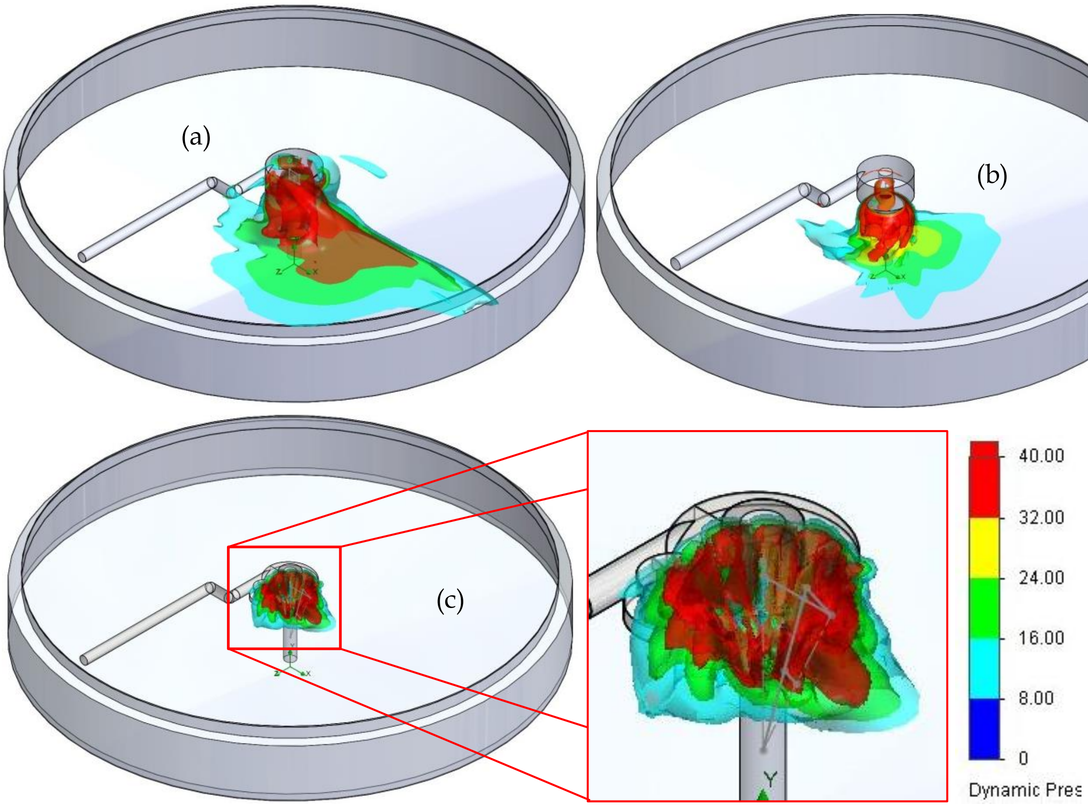

Figure 7. Dynamic pressure iso-surfaces surfaces at 40 Pa (red), 20 Pa (green) and 10 Pa (cyan) surrounding (a) an open feedwell, (b) closed feedwell and (c) the Radflow feedwell.

CONCLUSIONS

When compared to standard industrial open and closed feedwells, CFD results indicate that the Radflow feedwell yields a marked improvement in:

1. Dissipating the energy of the incoming feed.
2. Eliminating high velocity tails or scouring patches from the pulp bed, thereby maximising the quiescent area in which solids can settle.
3. Distributing the flocculated feed axi-symmetrically into the thickener body, which is thought to even out the load seen by the rakes.
4. Reducing the degree of radial recirculation, yielding low localised rise rates at the thickener walls

The above reasons are believed to be responsible (in large part) for the marked improved performance of the Radflow feedwell retrofits over the originally commissioned open feedwells (with auto-dilution slots) at the Ezulwini CCD thickener circuit.

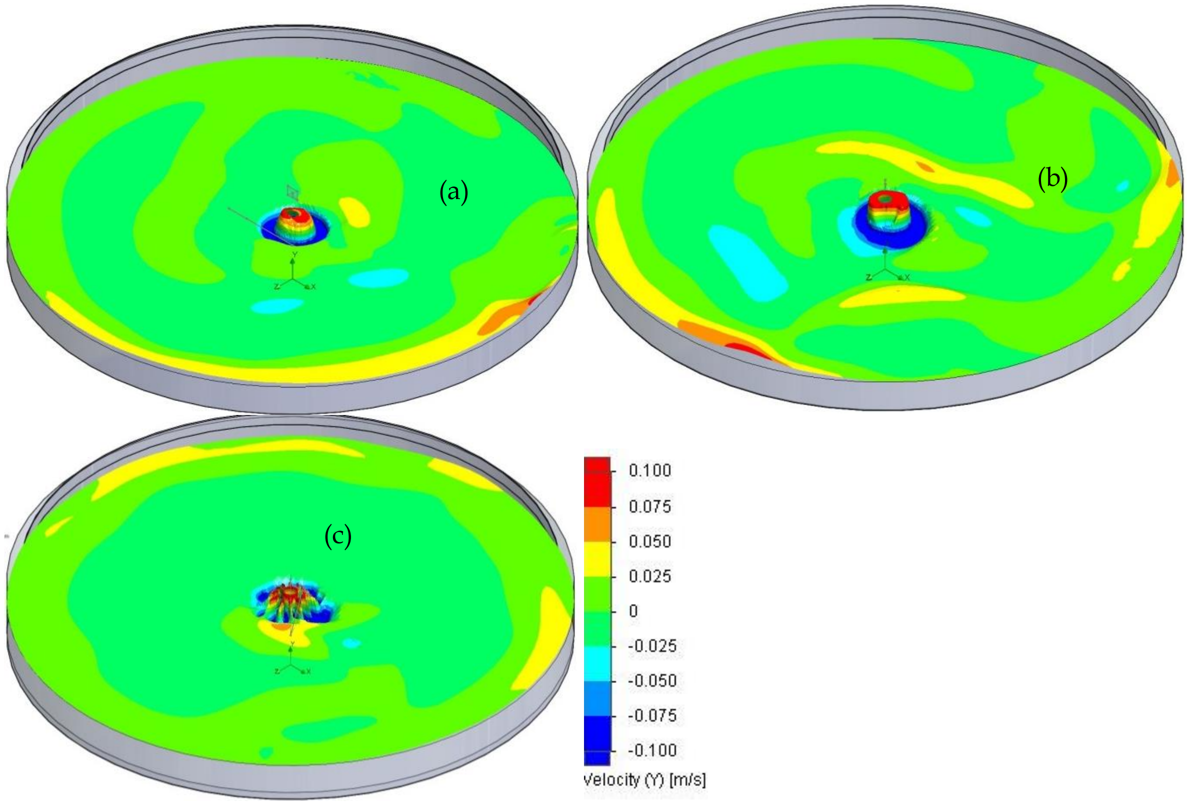

Figure 8.Vertical velocity contours across the thickener area for a thickener using (a) the open feedwell, (b) the closed feedwell and (c) the Radflow feedwell.

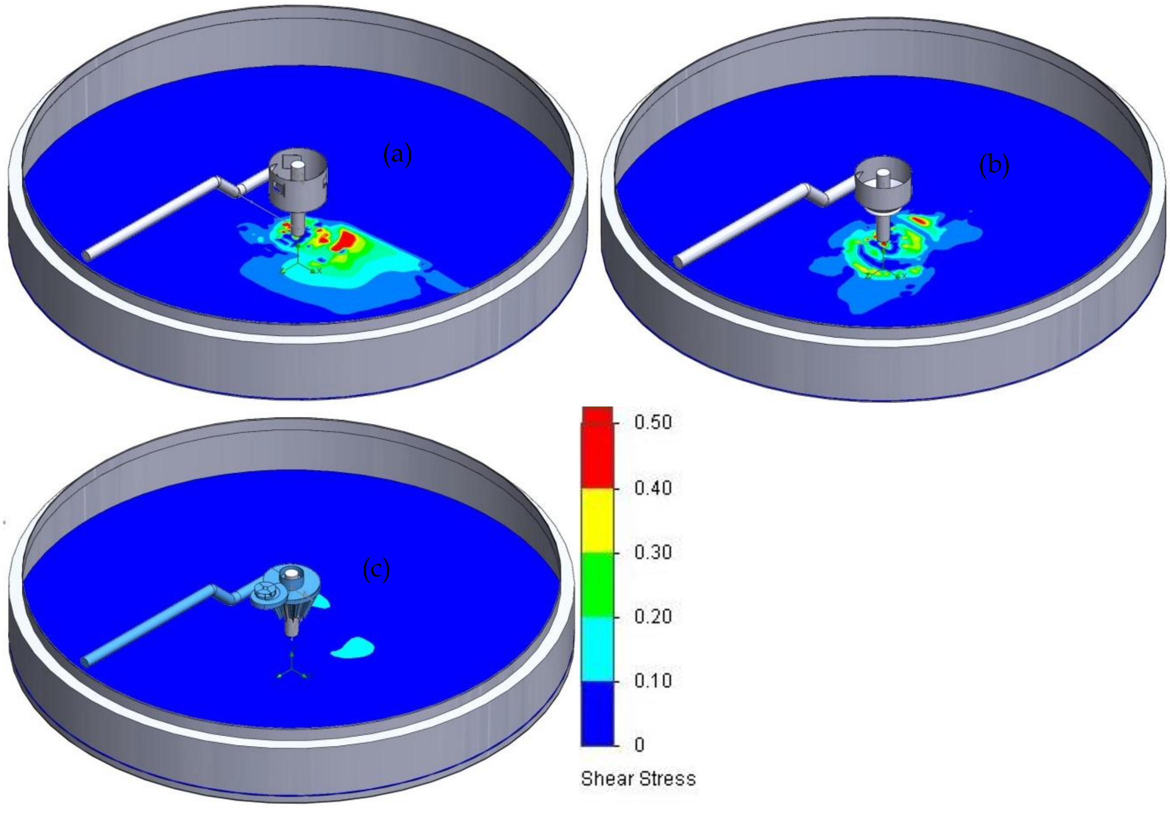

Figure 9. Shear stress contours on the compaction-zone interface for (a) the open feedwell, (b) the closed feedwell and (c) the Radflow feedwell.

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