Fluid Flow Characterisation of Process Equipment using Ultrasonic Pulsed Doppler Technique

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The measurement of fluid flow patterns within pilot or large scale process vessels is an important step in understanding their base-line behaviour and optimising operating performance. Traditionally, velocity measurements within such vessels could not be readily carried out using laser based techniques due to their size and often, due to the non-transparent nature of the slurries encountered. This has changed with the advent of the UVP (Ultrasonic Velocity Profiling) system, with Doppler echoes used to quantify velocity measurements along the beam path. This paper deals with the application of UVP to obtain velocity flow patterns within a pilot-scale "feedwell", a key element of gravity thickeners, in which the incoming feed energy is dissipated and particle aggregation can be induced to enhance solid-liquid separation. Critically, UVP has highlighted the highly turbulent and unsteady nature of the flows, something that had not been previously considered with other measurement techniques. The results obtained not only provide a useful insight into feedwell flow behaviour but also enable the development and validation of new designs using CFD (Computational Fluid Dynamics) modelling.

Keywords: Process industry, pilot-scale, process equipment, feedwell, UVP, CFD modelling.

1 INTRODUCTION

Solid-liquid separation is a key stage in wastewater and mineral processing operations. For applications in mineral processing requiring high throughputs of fine particle feeds, this process is most commonly achieved through gravity thickeners. They will be found within most hydrometallurgical flowsheets, often performing multiple duties that can include pre-leach thickening, liquor clarification, residue washing (counter-current decantation), concentrate dewatering and paste tailings production.

While thickeners can take on a range of sizes and geometries, they typically comprise of a cylindrical feedwell to which the feed is delivered, surrounded concentrically by a much larger, deeper tank that forms the main body for sedimentation [1]. The primary function of thickener feedwell was originally to dissipate the feed stream momentum and achieve uniform discharge to the sedimentation zone. Feedwell use as a *'flocculation reactor'* is a relatively recent innovation, largely a consequence of the introduction of synthetic polymer flocculants in the 1960s to enhance throughputs [2]. High molecular weight flocculants (typically acrylamide and sodium acrylate copolymers) aid in fine particle aggregation and in turn greatly enhance settling. Due to the high molecular weight and viscoelastic nature of flocculant solutions, their mixing hydrodynamics (also studied by the current authors [3]) within the slurry feed is crucial in controlling flocculation kinetics [4]. The efficiency of this process may also potentially influence underflow density and overflow solids losses.

White et al. [5] showed previously that physical investigations focussing on fluid flow within the main tank rather than the feedwell did not recognise (as discussed above) the importance of the feedwell. Where feedwells have been considered, the techniques used to measure velocities had an error band of 20% or higher and the feedwell designs were usually oversimplified. Velocity measurements in more realistic feedwell geometries using laser-based techniques were carried out by Sutalo et al. [6, 7] and White et al. [5], wherein the associated errors were about 3%. These detailed measurements were restricted to single-phase flow within laboratory scale feedwells. While this data was useful in its own right to validate a single-phase Computational Fluid Dynamics (CFD) model, detailed CFD studies show that single phase fluid structures bear no semblance to the multi-phase flows found in feedwells.

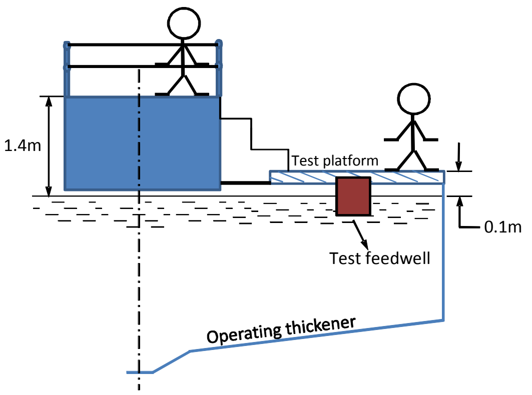
Until now, the opaque nature of multi-phase systems limited the choice of measurement techniques that could be used to quantify their flows. Advances over the past decade have made it possible to use UVP (Ultrasonic Velocity Profiling) system to measure such multi-phase flows. This paper presents detailed flow measurements performed inside a pilot-scale feedwell. UVP was able to highlight for the first time the unsteady and transient nature of the flows encountered within such feedwells.

2 EXPERIMENTAL SETUP

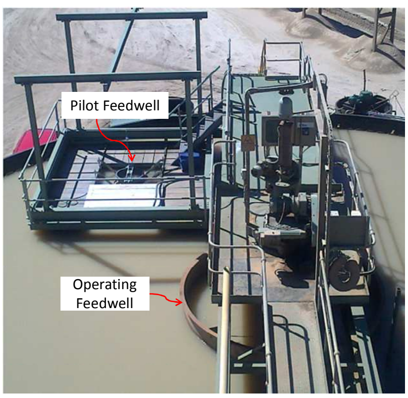
Earlier investigations revealed that flows within the pilot feedwell and its discharge could be strongly coupled to the outer surrounding tank. In order to capture a more realistic flow behaviour of the feedwell independent of its surroundings, a platform was constructed to conduct pilot-scale studies within the clarification zone of an operating thickener. Figure 1 shows a schematic of the pilot scale facility, as well as a photograph of the installed platform.

The measurement grid used for flow mapping is shown in Figure 2a and the vertical plane of measurement (red centreline) in Figure 2b. The diameter of the feedwell used in the present study is 0.6 m with a depth of 0.85 m. A shelf (60 mm wide, 6 mm thick) was located within the feedwell at a depth of 250 mm from the free surface. The flow enters the feedwell through a tangential inlet pipe (48 mm ID) placed just above the shelf. For single phase flow measurement with no solids, the pressure from the mains water supply was sufficient to achieve the required flow rate, with a flow meter and flow control valve used to regulate the desired flow rate to the feedwell. For two-phase flow measurement, slurry was pumped to the feedwell to achieve the required flow rate.

All measurements were conducted with a UVP Monitor (Model UVP-Duo) Met-Flow unit [8]. A 1 MHz transducer was used to measure the axial (vertical) velocities, while a 2 MHz transducer was used for radial (horizontal) velocities. The intersection of these two transducer beams in a selected measurement plane enables the 2-D vector to be obtained by simple vector addition at that point of intersection. A time averaged velocity profile was obtained by averaging 100 s of data.



(a)



(b)

Figure 1 Schematic (a) and photograph (b) of the installed platform for UVP measurements

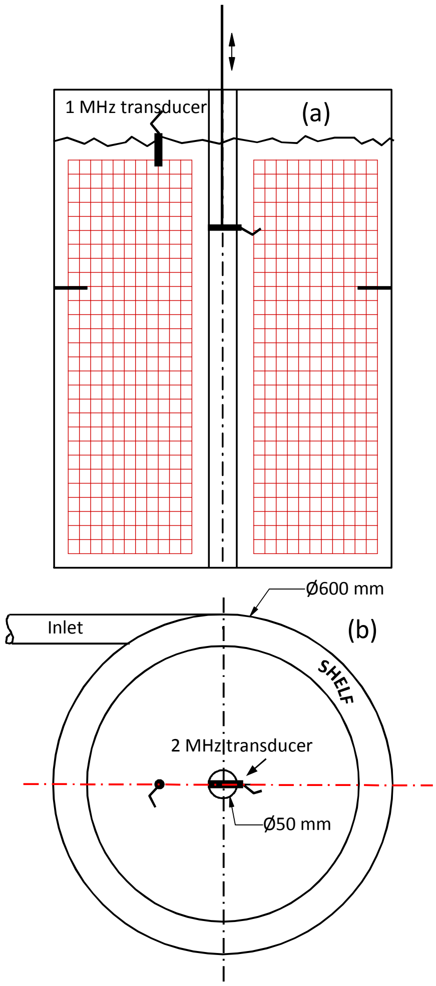


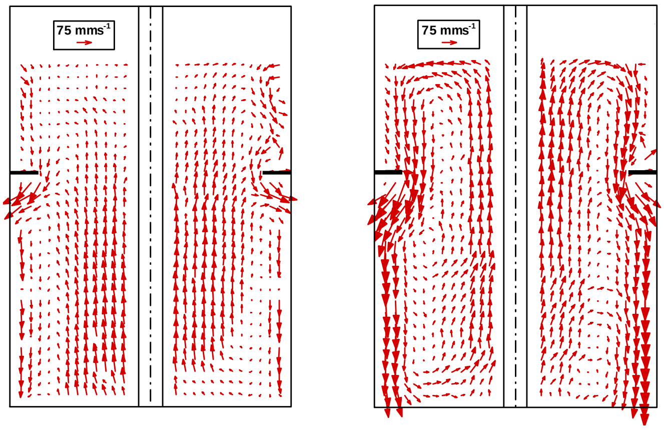
Figure 2 Measurement schematic

3 RESULTS AND DISCUSSION

3.1 Detailed Flow Map

The detailed flow map consisted of velocity measurements within the entire feedwell from the free surface right down to the discharge. The measurements were carried out at 20 mm intervals along the radial direction, while the measurement interval was 25 mm along the axial direction. A total of 80 measurement locations were considered for a flow map of the entire plane across the diameter of the feedwell.

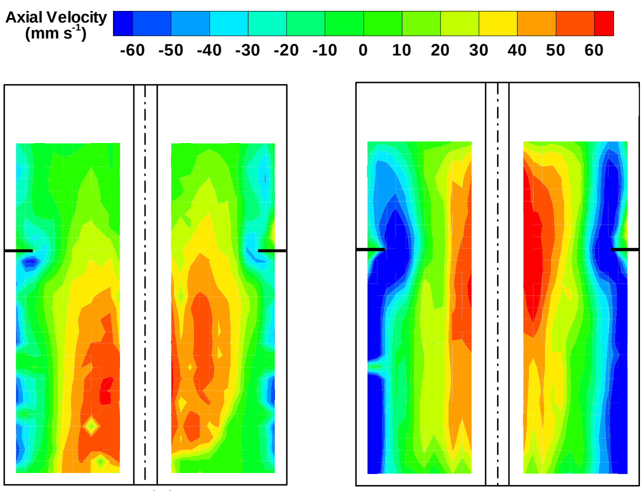
The inlet feed velocity for the detailed flow map was maintained at 1 m s $^{-1}$ for both the presence and absence of solids. Figure 3 shows the time averaged flow velocity vectors inside the feedwell for both water and 6%w/w solids. It can be seen that there is an up-flow along the entire central shaft of the feedwell with a down-flow close to the feedwell wall. This gives rise to recirculation regions both above and below the shelf. For the same inlet velocity, the flow in the presence of solids has a more pronounced effect with a larger downward momentum (near the feedwell wall).



(a) (b)

Figure 3 Detailed time averaged 2D flow map (a) Water (b) Solids at 6%w/w

Figure 4 shows contour plots of the axial velocity for both cases. The dark (red) colour signifies flow moving upwards, blue flow downwards. From these contour plots the degree and extent of natural dilution (i.e. flow into the feedwell) can be assessed. Natural or forced (through mechanical devices) dilution is an important aspect of feedwell performance; high solids dilution generally favours larger aggregate sizes, while dilution flows can also be utilised to promote adequate mixing between the slurry and the viscoelastic flocculant solution. For the water case, the "dilution" flow is confined mostly below the shelf, while the solids case shows dilution flow prevalent over the entire depth of the feedwell.



(a) (b)

Figure 4 Time-averaged axial velocity contours (a) Water (b) Solids at 6%w/w

3.2 Targeted Flow Map

Based on the detailed flow mapping results, targeted measurements to study the effect of inlet flow rate and/or solids concentration were conducted 25 mm on either side of the shelf for the left plane shown in figure 3b. Table 1 shows the process conditions for the targeted flow measurements.

Figure 5 and Figure 6 shows the time averaged 2D velocity vector map for the low and high flow conditions, respectively. Near the feedwell wall, the flow moves downwards in proximity to the shelf, both above and below it. Halfway across the measurement plane towards the central shaft, the flow changes direction and starts to move upwards. The velocity vector pattern for all conditions remained the same while the magnitude of the vectors increased with the solids concentration and inlet velocities (high flow condition). This increase is mainly attributed to the density currents setup by the solids plunging close to the feedwell wall, causing an upwelling of liquid (or dilution) close to the central shaft.

Table 1 Process conditions for targeted flow map

Designation	Inlet velocity U_o (m s^{-1})	Solids concentration (% w/w)
Low flow	0.5	0, 3 and 14%
High flow	1.0	0 and 14%

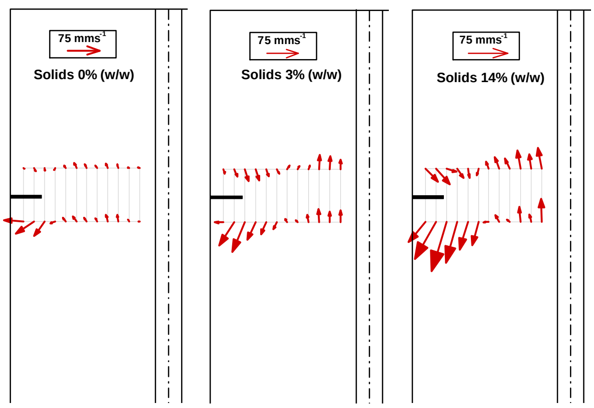


Figure 5 Time-averaged 2D velocity vectors for *low flow*

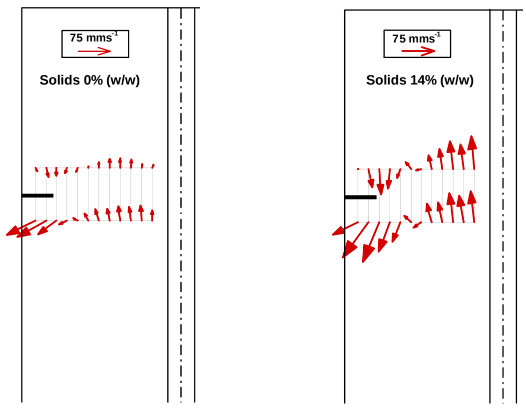


Figure 6 Averaged 2D velocity vectors for *high flow*

3.3 Axial Fluctuations

In order to better understand the turbulent and unsteady nature of flow inside the feedwell, axial velocity fluctuations, which indicate the deviation of instantaneous velocities from its mean, were plotted across the feedwell width in the shelf region. Figure 7 plots the fluctuations of axial velocity for the measurement period above and below the shelf at high inlet flow velocities. The x-axis shows the radial distance in the feedwell, starting from the centre (0 mm) and moving towards the feedwell wall (-300 mm) in this measurement plane. The black dashed line represents the extent of the shelf away from the feedwell wall. The fluctuating velocities plotted along the Y-axis have been normalised relative to the inlet velocity.

There is a noticeable increase in fluctuations that corresponds with the increase in solids concentration; the presence of solids seems to create more unsteadiness within the feedwell. This was observed across all the process conditions tested. The axial fluctuations show a general increase from the feedwell wall to the edge of the shelf. Across all conditions tested for the no-solids (water) case, peak fluctuations were recorded at the shelf edge, which may be attributed to the flow separation. Past this location towards the central shaft, there was a decreasing trend before flattening out.

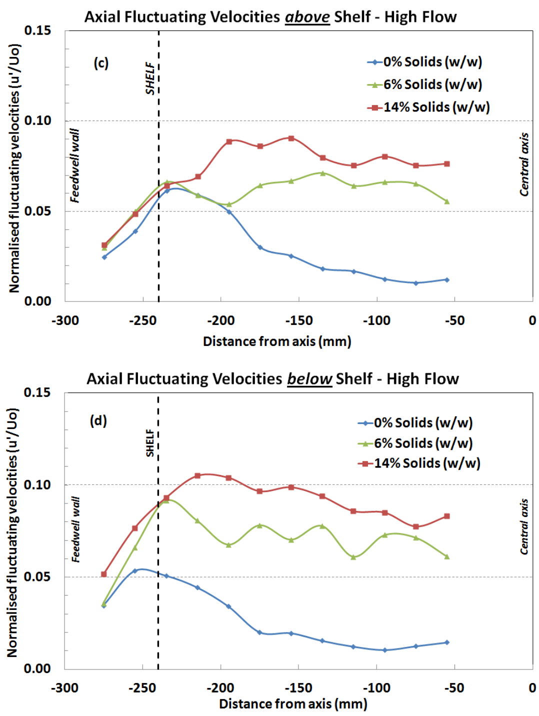


Figure 7 Axial fluctuating velocities above and below the feedwell shelf measured by UVP high flow

Flow velocity data of this nature could not previously be obtained in a pilot-scale feedwell using other available measurement techniques. The ability of UVP to quantify flow fluctuations has provided the first physical evidence to support CFD predictions of flow instabilities within single tangential inlet feedwells. The velocity data generated here will assist in the development and validation of two-phase CFD models used for predicting flows in full-scale feedwells; such models are being used to identify design and operating strategies to enhance existing feedwell performance, as well as propose new feedwell designs.

4 CONCLUSION

The UVP system was used to measure and characterise flow patterns inside a pilot-scale feedwell fitted with a shelf. Two different inlet flow conditions and three different feed solids concentrations were considered for these studies. Detailed flow mapping inside the feedwell was carried out on one plane for two selected conditions with targeted flow mapping for the remainder of the operating conditions tested. It was found that upward dilution flows near the central shaft increase with the solids concentration due to the density gradients setup by the solids. This ultimately leads to a corresponding increase in velocity fluctuations and unsteady feedwell flow behaviour.

ACKNOWLEDGEMENT

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