17th Australasian Fluid Mechanics Conference
Auckland, New Zealand
5-9 December 2010

Application of Ultrasonic Velocity Profiler (UVP) in the Minerals Industry

K. Mohanarangam, W Yang and K Simic
CSIRO Process Science and Engineering (Parker Centre), P.O. Box 312, Clayton South, Vic 3169, Australia

Abstract

The minerals industry faces the constant pressure of optimizing processes to reduce production costs, whilst at the same time seeking ways to improve their environmental performance. Largely these objectives can only be achieved through improvements in technology. One critical area is the development of a better understanding of fluid flow patterns within large-scale process equipment. In this paper we describe how UVP has been used to quantify flow patterns in laboratory-scale and full-scale equipment of relevance to mineral processing operations. In particular, we describe outcomes from the application of the UVP-Metflow system to study various hydrometallurgical applications, including determining flow patterns within full-scale solvent extraction units and the mixing of viscoelastic flocculant solutions. This work has been carried out to support the further development and validation of CFD models that are being used to enhance the design of industrial processes.

Introduction

Solid-liquid separation is a common practice in the wastewater and mining industries. Suspended solid particles are separated from the solid-liquid mixture, with the recovered liquid either recycled or processed to recover valuable material. While filtration can be used, the immense volumes that require treatment in mineral processing leads to gravity sedimentation being the only practical option.

Thickeners are large sedimentation vessels, usually consisting of a cylindrical feedwell, surrounded concentrically by a much larger, deeper tank which forms the main body of the thickener. Slurry is fed into the feedwell along with a high molecular weight flocculant to induce the aggregation process under turbulent mixing conditions. The aggregates are discharged from the feedwell to settle under gravity to form a concentrated underflow (suspension of solids) at the bottom of the tank. The clarified liquor on the other hand flows over the outer edge of the upper surface of the thickener (overflow). Industrial thickeners may be up to 100 m in diameter, with feedwells up to 15 m across.

Feedwells are primarily designed to dissipate the feed stream's kinetic energy, helping to achieve the uniform settling with minimum turbulence, and thereby reducing/eliminating short-circuiting within the thickener [1]. Feedwell use as a 'flocculation reactor' is a relatively recent innovation, a consequence of the introduction of synthetic polymer flocculants in the 1960s [2].

High molecular weight flocculants (typically solutions of high copolymers of acrylamide and sodium acrylate) aid in fine particle aggregation and in turn greatly enhance settling. Due to their high molecular weight and viscoelastic nature, their mixing hydrodynamics within the slurry feed is crucial in controlling flocculation kinetics [3], also potentially affecting underflow density and overflow solids losses.

It has been shown that the mixing lengths in pipe flow of dilute polymer solutions can be several times larger than those for Newtonian flows [4]. These mixing lengths not only affect the flow at the mean velocity level but are known to affect the turbulence level in mixing [5,6]. In this paper, the effect of flocculant mixing in water was studied as a function of mixing conditions and flocculant concentrations in a coaxial linear pipe using a Metflow Ultrasonic Velocity Profiler (UVP) unit [7].

In addition to the lab-scale measurements above, a full-scale plant study was undertaken in a SX (Solvent eXtraction) settler. SX involves the selective extraction of dissolved metals from one miscible phase to the other. A leach solution is mixed with an organic solvent (often containing extractant chemicals). The organic and aqueous phases form an emulsion, during which metal ions transfer to the organic phase. The mixture is allowed to settle and the phases then separate (organic on top) prior to further processing, Flow mapping during the separation of both phases was carried out in a settler unit using the Metflow UVP unit [7].

In both cases, characterising the flow has provided invaluable information, either for CFD model validation or for model development. It has also demonstrated the applicability of UVP across vastly different scales of operation.

Experimental Set-up

Laboratory-Scale

The experimental rig consisted of two coaxial linear pipes, a schematic of which is shown in figure 1. The outer transparent plastic tube (a) had a 25.4 mm OD and 19 mm ID, while the inner steel tube (b) had a 6.35 mm OD and 4.35 mm ID. Care was taken in positioning the inner tube to ensure it was situated at the centre of the outer pipe. This is done using several specifically-machined spiders. The spider located nearest to the nozzle was positioned at least 10 pipe diameters, so that the boundary layer formed in the pipe was fully developed before mixing with the water.

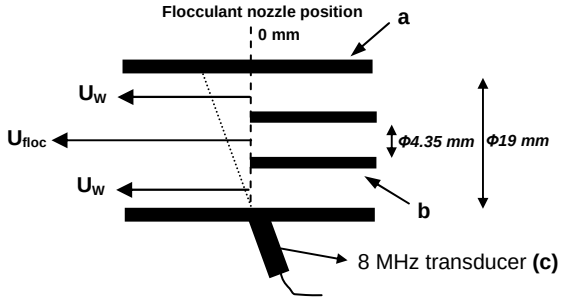

Figure 1: Schematic of the test section

Water was run directly from the mains to the outer pipe through a flow control valve that regulated the flow in order to achieve two different flow configurations viz., one where the centreline velocity of the inner steel pipe (jet) was greater than the outer pipe and vice versa. A Mono pump was used to meter the flocculant into the inner pipe.

An 8 MHz transducer (c) was used in this study. It was placed outside the transparent pipe using a specially designed housing giving the user the choice of various mounting angles around the pipe's circumference. However, in this study the results were obtained by positioning the transducer at the bottom of the pipe to avoid any unforeseen bubbles from corrupting the data. The housing was also designed for the transducer to be inclined at an angle of 20°, irrespective of its circumferential orientation.

Flocculant

The flocculant used in this study was Magnafloc 336 (Ciba Specialty Chemicals, now BASF), a powder product with ~30% anionic character and a nominal molecular weight in the range 15-20 million. A 0.5%(w/w) stock solution was made by carefully adding flocculant powder to water under strong stirring. This was then diluted to produce three different concentrations (0.2, 0.05 and 0.0075%). The effect of ionic strength on flocculant mixing behaviour was also investigated. Two sodium chloride (salt) concentrations (0.02 and 0.2 M) were investigated for the three flocculant concentrations. For these solutions, the required amount of salt was first mixed in the water prior to the powder addition during stock preparation.

Plant-Scale

The plan view of the settler unit is shown in figure 2; it measures about 28.5 m wide and 32.6 m long. However, only the area highlighted in green provided access for measurements.

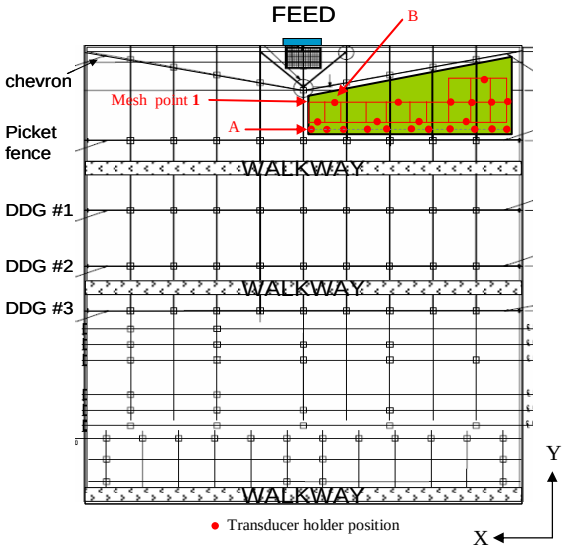

Figure 2: Plan view of SX settler, UVP measurement area shown in green.

Seven ultrasonic transducers with a low frequency of 0.5 MHz were chosen for their good propagation abilities in the large scale of the settler, since the attenuation of electric-to-acoustic efficiency is proportional to the square of frequency. Under the condition of relatively low fluid velocity inside the settler, the maximum measuring distance of the 0.5 MHz transducer was approximately 3 m along its axis.

Experimental Procedure

Laboratory-Scale

The effect of flocculant mixing was measured at four positions, with the 0 mm location almost coinciding with the tip of the flocculant pipe (figure 1). The other three locations were 30, 75 and 150 mm from the tip. Two velocity variations were trialled to study the effect of flocculant mixing, one where the jacket water velocity was higher than the flocculant jet and the other where the jet velocity was higher than the water velocity. To achieve this, the flow rate on the flocculant pipe was maintained at 0.5 L/min while the flow rates of the water were changed to be 20 L/min ($U_{floc} < U_w$) and 6 L/min ($U_{floc} > U_w$), respectively.

All the measurements were carried out with a UVP Monitor (Model UVP-Duo) MET-FLOW unit using an 8 MHz transducer with 4 cycles and 1024 repetitions. The flow velocity resolutions for the low and high flow rates were approximately 8 and 14 mm/s, respectively. In the absence of direct measurements the velocity of sound through the flocculant(s) is unlikely to be different from water due to the low concentration of the flocculant. The speed of sound for all the runs was kept constant at 1480 m/s. A 300 profile average was found sufficient for a statistically stable solution, increasing beyond this number caused the mean flow behaviour to change less than 1% .

Plant-Scale

A measurement mesh was pre-set with 26 cross points to represent the two-dimensional flow pattern (red lines in figure 2). A minimum number of 22 transducer holder positions (red dots) were carefully chosen to obtain 2D velocity components in both X and Y directions at each cross point. For instance, for the mesh point 1, the Y direction transducer in position A would provide the measurement of flow velocity in Y direction, V1, while the X direction transducer on the left side of disk in position B would provide the flow velocity, U1, in X direction. Therefore the 2D velocity vector at mesh point 1 was determined.

Two Perspex transducer holding disks were set at vertical heights of 700 and 1400 mm above the bath bottom for the velocity field measurements in aqueous and organic layers, respectively. Unfortunately, no measurements could be obtained at the 1400 mm height in all 22 positions. It was believed that the upper transducer holding disk was in the two-phase dispersion layer. Only aqueous phase velocity field measurements are presented in between the chevron and picket fences. A detailed outline of the measurement setup and procedure can be found in Yang et al. [7].

Results and Discussion

Laboratory-Scale

In this section, the mixing characteristics of different concentration flocculants along with varying salt contents are studied. A non-dimensional distance r* is used to represent the distance across the pipe diameter, where r*=0 represents the pipe wall and r*=1 represents the centreline of the pipe. Velocity profiles are only presented up to the centreline of the pipes.

$U_{floc}>U_W$

Figure 3 shows the mixing behaviour at four different locations wherein $U_{floc} > U_w$. In all the runs carried out, mixing of water with water was also studied in order to establish its behaviour relative to the high molecular weight flocculant solutions. Figure 3a shows the effect of flocculant mixing with no salt (0 M), whereas figures 5b and 5c show the effect of salt concentrations on the flocculants at 0.02 and 0.2 M, respectively. While the non-invasive nature of the UVP measurements is an advantage, the figures show that the technique does not resolve the turbulent boundary layer of the pipe wall accurately.

From figure 3a it can be seen for each case the velocity of the fluid jet at the pipe exit is of the same magnitude. Moving down the pipe to the next station (30 mm from the tip of the jet pipe) the momentum of the jet had dissipated to a similar degree except for 0.2% flocculant. This trend also held true for stations farther away from the jet (75 and 150 mm). For the 0.2% flocculant solution it appears that mixing was highly constricted, the effect

of which can be seen by a decrease in the velocity of flocculant in the jet region.

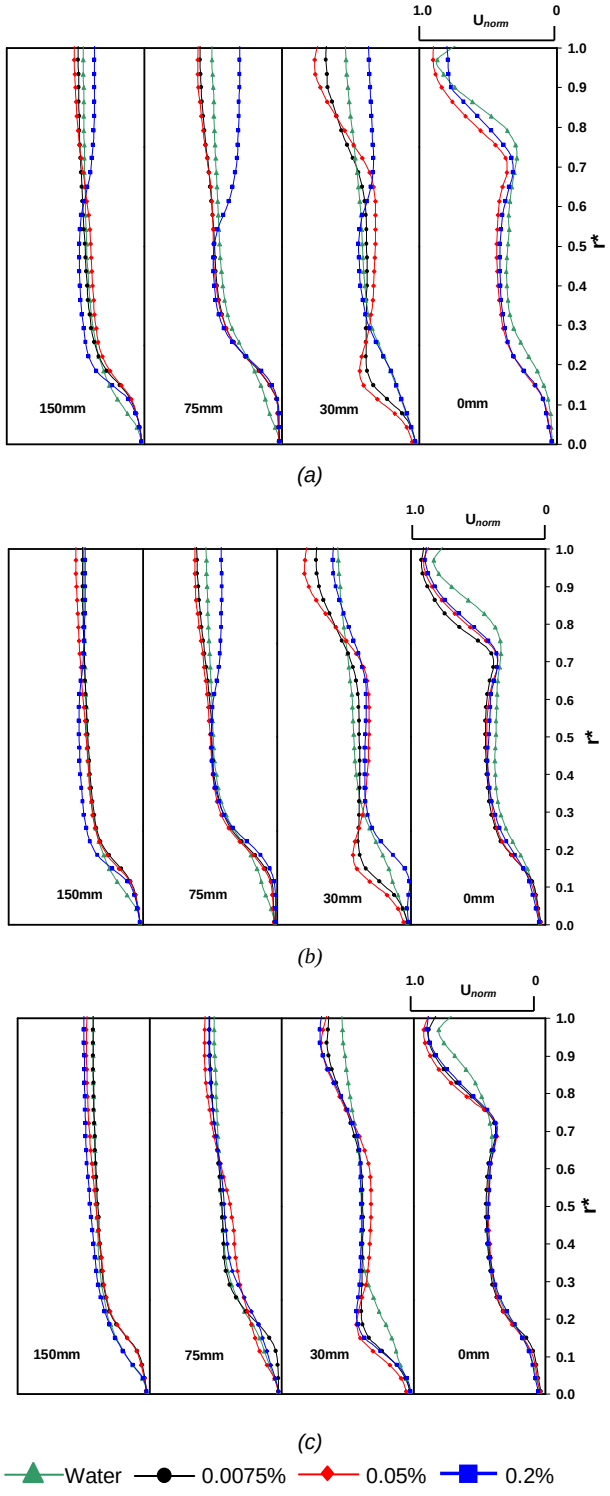

Figure 3: Normalised velocities (U_{norm}) showing flocculant mixing characteristics downstream of the flocculant pipe at 0, 30, 75 and 150 mm. when $U_{floc} > U_W$ (a) with no salt (0 M) (b) 0.02 M salt (c) 0.2 M. salt.

Figure 3b shows equivalent results for flocculant solutions at 0.02 M salt. It can be seen that at 0 mm, the velocities of all the fluids coincided with each other, whereas on moving farther away from the jet exit, the water as well the flocculants of concentrations 0.0075% and 0.05% were more dispersed than the 0.2%. The mixing of the highest concentration flocculant shows an interesting behaviour wherein, it tries to maintain the momentum of the jet at the 30mm station. However, for the same flocculant at 75 mm station the loss of momentum was similar to the 0 M case. This reduction is observed prominently close to the jet region. This momentum loss was continued further into the 150 mm section with the attenuation effect being less pronounced. Most of the other fluids appeared to have thoroughly mixed at this point.

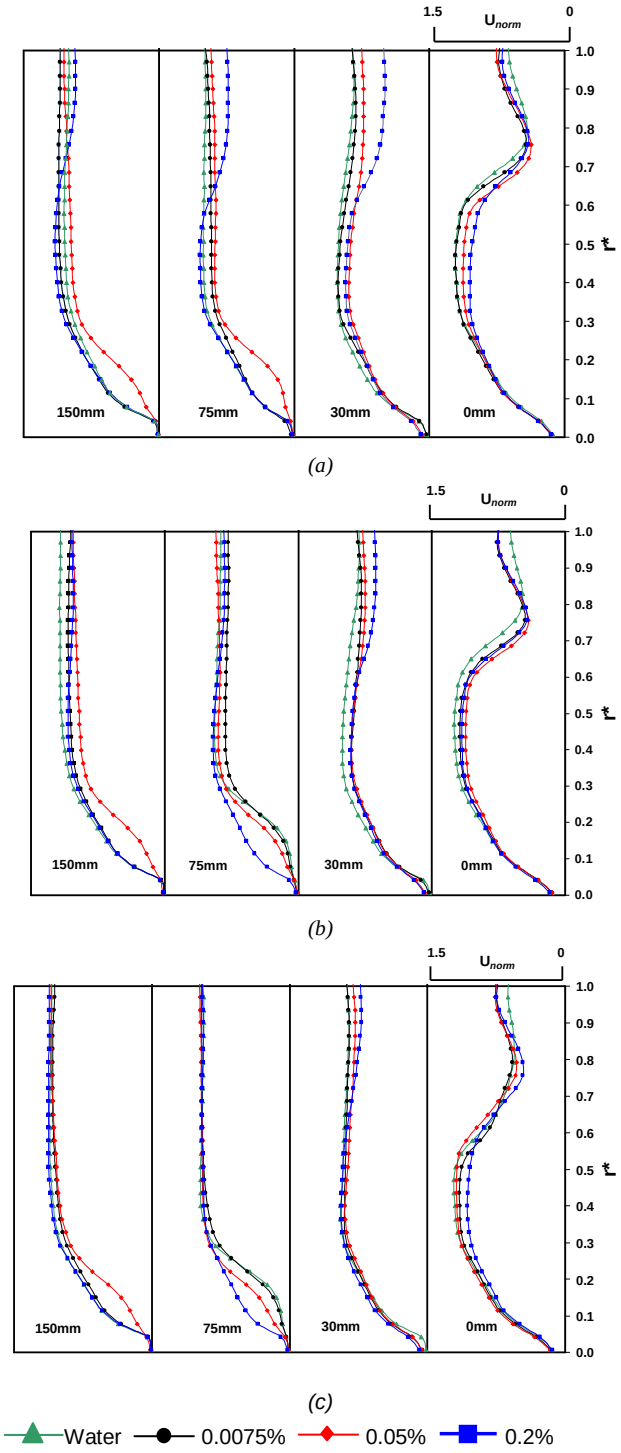

Figure 4: Normalised velocities (U_{norm}) showing flocculant mixing characteristics downstream of the flocculant pipe at 0, 30, 75 and 150 mm. when $U_{floc} < U_W$ (a) with no salt (0 M) (b) 0.02 M salt (c) 0.2 M. salt.

Figure 3c shows the mixing behaviour of flocculants with 0.2 M salt. It can be seen that the mixing behaviour of the flocculants improved greatly with the addition of the salt, tending to mix readily within a shorter distance of the jet exit. Jet prominence

was visible at 0 and 30 mm, while at 75 and 150 mm the jets had mixed thoroughly with the surrounding water to almost depict a fully developed profile.

$U_{floc}<U_W$

Figure 4 depicts the effect of flocculant mixing when the velocity of the water jacket is higher than the flocculant jet. Here again figures 4a, 4b and 4c represent results of flocculants at 0, 0.02 and 0.2 M salt, respectively.

From the results presented above, it can be stated that the higher concentration flocculant solutions required much longer mixing lengths. These mixing lengths were reduced as the ionic strength is increased. The solution dimensions of anionic flocculants are known to decrease at high ionic strength, with the presence of solution cations effectively "shielding" repulsions from the charged groups along the polymer chain, allowing the polymer to take a more coiled conformation.

The behaviour exhibited by the highly concentrated flocculant solutions is attributed to the viscoelastic nature of the long chain acrylamide/acrylate copolymers. Such effects are not well captured within CFD, but given the relatively short residence times within the turbulent feedwells (~10-50s), quantifying flocculant mixing is crucial towards accurate predictions of feedwell performance.

In most cases of flocculant mixing presented in this paper, the momentum from the flocculant jet did not match with the outer water jacket momentum. While this may be due to the underlying viscoelastic nature of the flocculant which inhibits mixing, this loss of momentum has not been captured elsewhere (increased momentum of water) by the UVP. This may be mainly attributed to the single line measurements carried out in this experiment. Work is now underway to circumferentially map the flocculant jet all around the outer pipe in a bid to capture this lost momentum.

Plant-Scale

Only a few results from the plant-scale measurements are discussed here; a full summary of results can be found in Yang et al. [8]. Figure 5 shows the 2D velocity vector and streamline plot of the aqueous phase at a height of 700 mm above the bath bottom. With the aid of a reference vector of 100 mm/s, the 2D vector plot indicates not only the direction of flow movement but also the magnitude of the velocity at each mesh point.

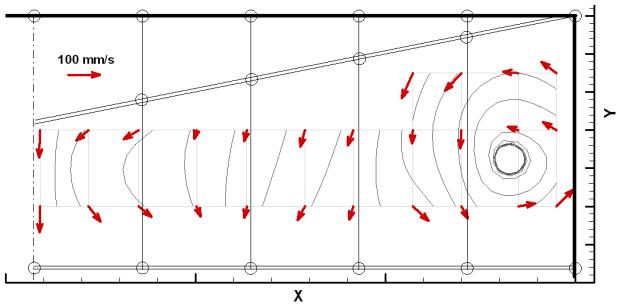

Figure 5: 2D velocity vectors and streamlines between chevron and picket fences (700 mm above base).

It can be observed that a high velocity, flow moved straight out of the chevron fence in the vicinity of the settler centreline with a magnitude of approximately 80 mm/s. Otherwise, the majority of the aqueous flow had a velocity range from 20 to 40 mm/s, except for a few points close to the outlet of the chevron fence. Moreover, a large flow recirculation zone can be seen in the right side corner of the settler, as is indicated by the flow streamlines. This was mainly due to the negative pressure field generated in the region by the bulk aqueous flow leaving the chevron fence with an angle towards the centreline of the settler. The centre of this recirculation zone was almost in the middle of the right corner structural section.

This recirculation upstream of the chevron was identified as undesirable behaviour for phase disengagement under normal settler operation. Further work is underway using CFD modelling to test prospective modifications.

Conclusions

In the current study, an UVP was used to study flocculant mixing in a laboratory-scale system and was also used to characterise the flow in a full-scale SX settler unit. The versatility of UVP was clearly demonstrated at extremes of scale and with industrial streams. UVP was able to readily distinguish the contribution of a flocculant jet in pipe flow in a non-invasive manner, providing real-time velocity measurements. The 2D velocity plane measurements on a full-scale settler were able to quickly capture features that were difficult to quantify by single point velocity techniques. In both applications, UVP is therefore expected to be an invaluable validation tool for CFD models currently being developed to describe fluid flows during the mixing processes.

Acknowledgments

Part of this work was conducted via the AMIRA project P266F: "Improving Thickener Technology". The authors acknowledge the financial support given to this research from the project sponsors. The support of the Parker Centre for Integrated Hydrometallurgy Solutions (established and supported under the Australian Government's Cooperative Research Centres Program) is also gratefully acknowledged.

References

[1] Fawell P.D., Farrow J.B., Heath A.R., Nguyen T.V., Owen A.T., Paterson D., Rudman M., Scales P.J., Simic K., Stephens D.W., Swift J.D. & Usher S.P. (2009). 20 Years of AMIRA P266 "Improving Thickener Technology" - How has it Changed the Understanding of Thickener Performance? 12th International Seminar on Paste & Thickened Tailings, 21-24 April 2009, Viña del Mar, Chile, pp. 59-68.

[2] Moody, G.M. (1995). Pre-treatment chemicals. Filtration & Separation, 32, pp. 329-336.

[3] Fawell, P.D., Owen, A.T., Grabsch, A.F., Benn, F.A., Labbett, D.M. & Swift, J.D. (2009). Factors affecting flocculation within gravity thickeners. Water in Mining 2009: Proceedings, 15-17 September 2009, Perth, Western Australia, The Australasian Institute of Mining and Metallurgy Publication Series No. 10/2009, AusIMM. Carlton, Australia, pp. 71-76.

[4] Ranade, V. & Mashelkar, R. (1993). Turbulent mixing in dilute polymer solutions. Chemical Engineering Science, 48(9), pp.1619-1628.

[5] Liberzon, A., Guala, M., Kinzelbach, R. & Tsinober, A. (2006). On turbulent kinetic energy production and dissipation in dilute polymer solutions. Phys. of Fluids, 18, 125101.

[6] Ouellette, N.A., Xu, H. & Bodenschatz, E. (2009). Bulk turbulence in dilute polymer solutions. J. of Fluid Mech., 629, pp. 375-385.

[7] Met-Flow SA. (2002). UVP Monitor Model UVP-DUO users guide. Metflow SA, Lausanne, Switzerland.

[8] Yang, W., Simic, K., Rajasingam, R., Chovar, M. & Schwarz, M.P. (2010). Copper 2010, June 6-10, 2010, Hamburg, Germany.