Residue Thickener Modelling at Worsley Alumina

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ABSTRACT

Production has been steadily increased at Worsley Alumina since 1988 and the corresponding requirement for additional residue handling capability has been met by cost-effective upgrades.

Research and Development projects have been an on-going priority on the residue settlers and washers and a number of initiatives have been introduced to ensure that residue handling capability is maintained by these tanks.

The most significant breakthrough on these tanks has been achieved due to the use of CFD modelling and associated tracer work. The development of the technical breakthrough at Worsley began with involvement in AMIRA thickener project 266A. Plant trials in cooperation with CSIRO using tracers plus CFD modelling led to a clear understanding of flow patterns and flocculant performance requirements. This information was used as a basis for testing feedwell modifications on a CFD model.

This paper outlines the use of CFD modelling on the tanks, the assumptions made and the benefits achieved by implementation of the information obtained.

1 INTRODUCTION

Western Australian Alumina producers use bauxite from the Darling Scarp which has low extractable alumina content by world standards and consequently residue handling facilities form a large part of the process.

2 BAYER PROCESS OVERVIEW

The alumina refinery process consists of four steps (Figure 1)

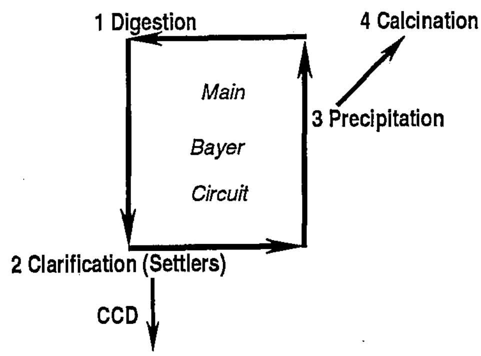


Figure 1 Process Overview

1 Digesting ground bauxite in hot caustic solution.

2 Separating the residue from the liquor in settlers.

3 Seeding the supersaturated cooled liquor with alumina hydrate and growing the hydrate to size.

4 Calcining the hydrate to produce alumina.

The settlers where the residue is separated from the saturated caustic liquor is the area of the process that this paper covers. Counter current washing (CCD) recovers most of the physically bound caustic soda in a two train three-washer circuit before disposal after final washing on mud filters.

As production increased the extra residue generated would have caused excessive additional soda loss unless technical advances were made.

The most critical tanks in the counter current decantation circuit are the settlers because they are on the main process loop and problems in the settlers can cause production losses. All new development work has therefore initially been carried out on these tanks.

2.1 Settlers

The Dorr Oliver settlers are 47 metres in diameter, approximately 11 metres high outward raking with a central rotating column and feedwell with centre top feed and bottom peripheral discharge.

Production has steadily increased since 1988 from 100 % of design (1 million tonnes of alumina per year). Figure 2 shows the steady rise in production, which is expected to rise even further by mid 1998 to 188 % of design.

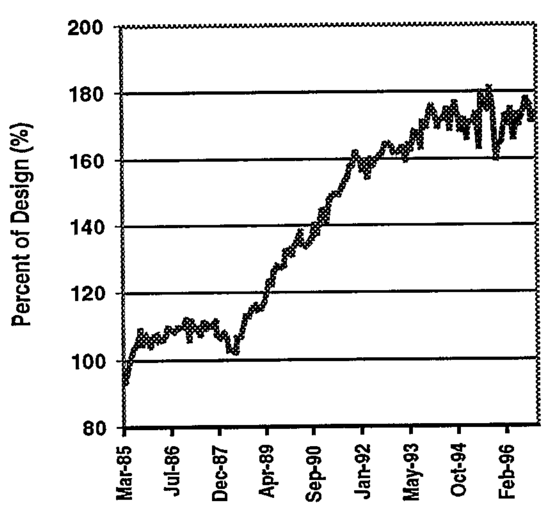


Figure 2 Alumina Production

2.2 CCD Circuit

This increase in production has been achieved without an increase in the number of tanks for residue handling. There are two settlers and six washers plus one spare tank that is used to replace a tank which is off for cleaning.

The following improvements and developments were carried out to increase capacity over the last 7 years;

- Feed forward / feed back computer loops on residue and flocculant.
- A new generation of flocculants was introduced.
- Flocculant addition was improved.
- Process parameters were smoothed.

3 AMIRA PROJECT DEVELOPMENT

In 1992 Worsley joined AMIRA Thickener Technology Project 266A because new options for improvement were becoming exhausted and a greater understanding of the settler process was required.

It was felt that performance of thickeners could be improved by optimizing conditions within the feedwell, although the optimum conditions which should be targeted were by no means well understood. It was believed, for example, that:

- Extent of feed dilution (either natural or forced) was important to the efficiency of flocculation; and

- Mixing between flocculant and feed within the feedwell and the subsequent shear rate history of particles as they leave the feedwell was critical to optimum separation of solids and liquor within the settling zone.

The first field visit as part of the AMIRA project concentrated on flocculant properties including mixing using field and laboratory equipment. The data collected during the visit gave a better understanding of flocculant mixing and dosing requirements and also provided valuable information for subsequent estimation of possible flocculant kinetics and flow patterns in the settler feedwell.

The second visit concentrated on determining residue and liquor flow patterns in the feedwell and also in the body of the tank.

3.1 Tracers

Two chemical tracers were used in the feedwell flow pattern studies. A halogenated carboxylic acid was used to trace the liquor through the whole of the volume of the tank. Lithium ion tracer was used to study the solids flow in the feedwell.

3.1.1 Lithium Ion Tracers

Lithium ion is unstable in the presence of red mud and precipitates from the caustic liquor after a time. Chemical analysis showed that a significant proportion of the lithium ion is rapidly adsorbed on the surface of the red mud and can be recovered. Therefore in the relatively short time required to pass through the feedwell, lithium ion acts mainly as a solids tracer. The forced convection occurring ensured that the hydrodynamic paths of red mud and caustic liquor were similar. This enabled the validity of lithium ion as a feedwell tracer to be proven by comparing its analytical recovery with that of a proven liquid tracer (Section 3.1.) known to remain in stable solution and to be unadsorbed by red mud.

3.1.2 Experimental Method

Lithium ion tracer dissolved in overflow liquor was added to the feed line and four metal tubes were inserted into the feedwell to enable samples of the liquor to be pumped continuously from four known positions. Because of the presence of rotating structural members, the sample tubes were inserted to only one third of the depth of the feedwell skirt. Samples of these pumped streams were collected at timed intervals and analysed for lithium.

It should be noted that this sampling occurred from a minute area of a distributed outlet. This was considerably more complex than typical text book or literature examples in which sampling occurs from a well mixed single stream. However, the relative recoveries obtained at the different sampling points, still provided valuable information.

3.1.3 Analysis for Tracer Results

Five tracer runs were carried out, but during the course of these runs, there was unavoidable variation in operating conditions. These included the feed flow rate, the height of the free surface above the feed pipe, the feed percent solids and the random nature of the turbulence in the feedwell. Consequently the five RTD curves for each sampling position were averaged.

3.1.4 Comparison of Experiment and Model

Because of the variety of uncontrolled factors, which influence transport of the tracer, it is impossible to compare different experimental runs on an absolute basis. Consequently, the tracer concentration data for each run was normalised to the height of

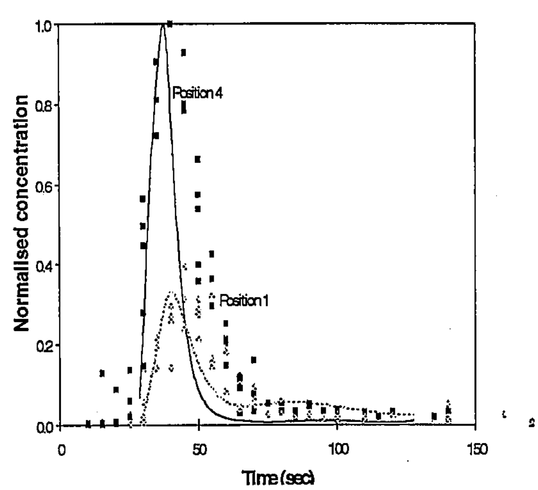
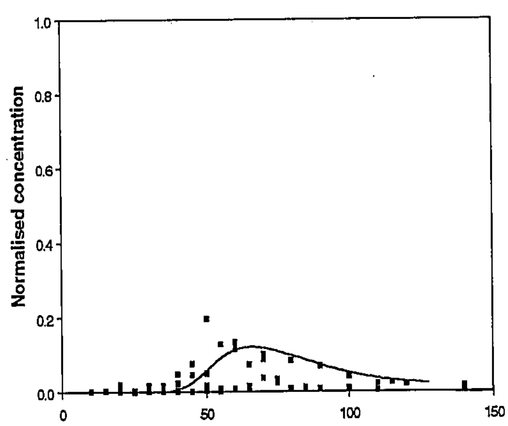


Figure 3 RTD Data Comparison (positions 1,4)

the highest peak (4). In addition, the normalised curves for each run were shifted as a set in time to allow the peaks of curve 4 from the different runs to coincide. The relative timing of the leading edges and the ratios between the peak heights within each run for the four sampling positions were preserved in this way. The simulated RTD curves were also normalised using the height of peak 4 as a reference.

A comparison of the simulation curves for two of the sampling positions with the experimental data for all runs for those positions is shown in Figure 3. In all cases, the measured peaks are more attenuated (spread) than the simulated peaks. The leading edge of the simulated curve for position 4 matched the corresponding data points. It can be seen that the leading edge of the simulated curve for position 1 was also a good fit to its points. The data for position 3 is shown in Figure 4 for clarity. In view of the small size of the peaks of position 3 and also position 2 the agreement between experiment and model is also quite acceptable and was considered to provide adequate validation of the CFD model for it to be used for design purposes.



4 RTD Data Comparison (position 3)

3.1.5 Feedwell Flow Patterns

The interpretation of these results led to preliminary development of flow patterns in the feedwell (Figure 5) which helped develop an understanding of the feedwell flow patterns and flocculant sparge locations. The flocculant should be located in the low solids part of the feedwell so that it can be diluted effectively before mixing with the residue solids.

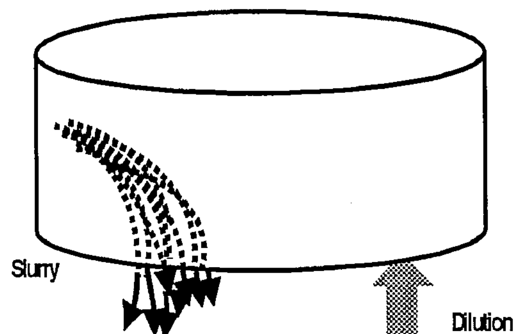


Figure 5 Feedwell Flow

4 CFD MODEL TWO PHASE

A two-phase computational fluid dynamics (CFD) model has been developed which allows prediction of concentration contours of suspended solids. In addition a simple equation describing the rate of adsorption has been incorporated in the two-phase model to show how far unadsorbed flocculant molecules travel through the liquor before being taken up by a particle surface. The model is used to compare different design changes to the feedwell and different positions of the flocculant sparge.

4.1 Liquid/Solids Flow Model

The solids concentration in thickeners is high, and varies significantly from one part of the tank to another. As a result, density currents can be induced and for this reason, flow must be simulated using a two-phase solids/liquid model. In this work a two-continuum (or "Eulerian-Eulerian") technique, the most advanced available, is used. Two sets of continuity and momentum equations are solved, one for each phase. The two sets of equations are coupled by means of common pressure and interphase momentum exchange terms (ie drag between the liquid and particles).

A single aggregate size has been assumed in the settling zone of the settler with the aggregate settling velocity taken to be 2 m/hr.

Only the part of the settler above the bed has been explicitly calculated in the model with the bed height taken from operating experience. At the bed surface settled aggregates are incorporated into the bed, and therefore removed from the computational domain. That is, a sink of solids is placed at the bed surface equal to the rate at which solids settle onto the bed. This technique yields a good approximation to the flow above the bed, and significantly reduces the time needed to run the model. While the bed could be modeled within the same simulation (using suitable hindered settling formulas), the action of a rake would have to be included to move solids to the underflow.

4.2 Flocculant Adsorption Model

The kinetics of the complete flocculation process (ie uncoiling / adsorption / bridging / aggregation etc) are not well understood, so the model is restricted to simulating the adsorption step. Simplifying assumptions have been made about other steps involved in the flocculation process. Furthermore, it is assumed in the model that:

1. Mixing between flocculant and liquor can be adequately described by turbulent mixing, with turbulence predicted by the κ-ε model.

2. Any further changes in conformation (uncoiling) of flocculant molecules can be neglected, the molecules being ready to attach to a solid surface.

3. Adsorption onto individual primary feed particles is the only step responsible for disappearance of free flocculant molecules from the liquor (bridging and subsequent steps are neglected).

The limits of adsorption are based on local fluid dynamic quantities calculated by the CFD code. Details of this will be given elsewhere.

Collisions due to Brownian motion are also accounted for, but the rate is usually orders of magnitude lower than the collision rate due to shear.

As the particles being flocculated within the feedwell are already aggregated, it is necessary to assume a porosity of the aggregated "particles". In the absence of better information, the aggregated "particles" are taken to be 95% liquid and 5% solid particles based on CSIRO measurements on similar systems. If the incoming aggregates have higher porosity, the net effect on the model is to increase the adsorption rate.

There is a limit to the amount of flocculant that can be adsorbed onto particles simply because the particles become completely covered with polymer molecules. Theoretical quantification of this saturation effect is difficult because it will depend on molecule shape, the interaction of molecules with the particle surface, chain flexibility etc. For the model used in this report the adsorption rate is multiplied by a factor $(1-p)^2$, where p is the coverage (ie the fraction of the maximum amount that can be adsorbed). The maximum adsorbed amount has been estimated on the basis of the molecules (thought of as spheres) fully covering the particles on the outer edge of the aggregates.

The saturation value thus calculated is 2.8×10^{-4} kg polymer per kg solids. This is lower than experimental value of $2\text{-}5 \times 10^{-3}$ kg/kg measured by Behl et al (1993), but is consistent, given that Behl et al were adsorbing onto unflocculated fine particles, whereas in our case adsorption is onto already flocculated particles.

4.3 Distribution of Adsorbed Flocculant

The simulation also keeps track of the amount of flocculant adsorbed onto particles. The computed distribution of adsorbed flocculant, as a fraction of the local solids mass by weight has been developed. This is a useful quantity to monitor because it is proportional to the coverage of particles by polymer molecules. Coverage is likely to be critical in subsequent flocculation steps, eg a desirable situation would be to have solids leaving the feedwell with a reasonably uniform coverage of flocculant molecules, possibly around 50%.

Flocculant coverage of particles near the flocculant sparge is high, whereas particles that exit the feedwell rapidly, have low flocculant coverage.

5 USE OF CFD MODEL

Once the parameters governing the liquid/solid/flocculant interactions are set the CFD model can be used as a development tool to design feedwell modifications to improve performance.

When applied to the existing configuration of a Worsley settler, it showed that the feed streams tended to sink out the bottom of the feedwell without mixing well. The feed which is directed towards the wall only moves a short distance around the feedwell wall before gravity pulls it downward and out of the feedwell. This occurs because the higher solids concentration of the feed stream makes it denser than the surrounding liquid.

The solids concentration in most of the feedwell is reasonably uniform at about 1.3% by volume (3.8% by weight): this is lower than the feed concentration because of natural dilution by low solids concentration liquor from outside the feedwell. The concentration in the feedwell is close to the 4-5% believed to be optimum.

Figure 6 shows the computed solids distribution on a surface just inside the feedwell skirt. Heavier shading indicates high solids concentration in the feed stream exiting the feed pipe. The feed streams are directed partly towards the wall, as shown by the velocity vectors.

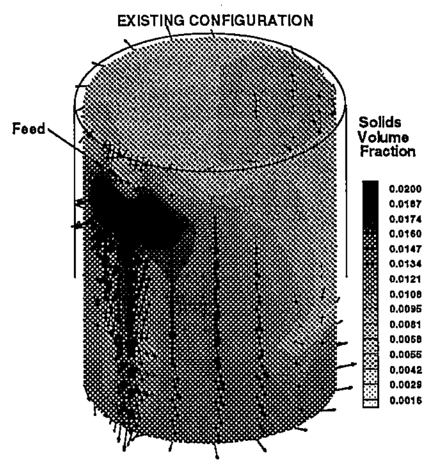


Figure 6 Solids Flow

With the adsorption kinetics assumed in this report, the comparatively small residence time in the feedwell results in a non-uniform coverage of particles by polymer.

When the flocculant sparge is moved closer to the feed pipes in the model, some parts of the feed received better coverage of polymer, but the non-uniformity remained. Furthermore unadsorbed flocculant still leaves the feedwell. Another further disadvantage of having the flocculant sparge near the feedpipes is that the flocculant is not mixed with natural dilution liquor before contacting the feed.

One other sparge position was tried in the existing configuration (sparge above feedpipes), but there was no apparent improvement. It therefore appears that it is unlikely that major improvement in performance would be obtained by moving the sparge position within the existing configuration.

The reason for this is likely to be the short residence time of feed within the feedwell. The feedwell was probably designed with the intention of the two feed streams moving in opposite directions around the feedwell wall and colliding at a point diametrically opposite the feed pipes.

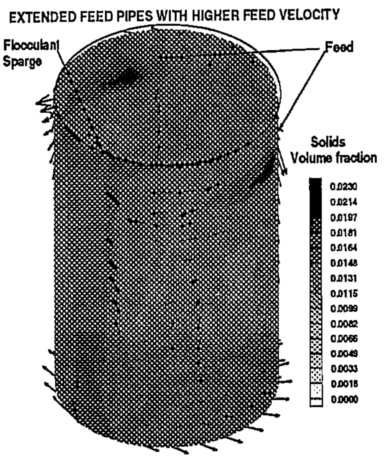


Figure 7 Model A Flow Patterns

Attempts were made to more closely approximate that intended situation by using alternative designs on the model. One of those tested was to extend the feedpipes around the walls and to increase the feed discharge velocity (Model A).

This modification (Figure 7) achieves the aim of the feed streams colliding on the opposite side of the feedwell where the mixing is good. The flocculant sparge may be placed at either (a) the slurry mixing point where adsorption is excellent but flocculant is not diluted before feed contact or (b) where the feed pipe enters the tank giving good dilution of the flocculant but poor adsorption on the slurry. The increased velocities resulting from the higher discharge velocity may lead to aggregate breakup.

5.1 Successful Model Modifications

The modification shown in Figure 7 did not give sufficient advantage to be trialed on full scale equipment. A number of other feedwell designs (Designated as Models B to D) were developed and tested using CFD modelling.

A successful model (Model C) for improved feedwell mixing was developed with a more radical design change. In this design the flocculant is all adsorbed in the feedwell and the polymer coverage of particles is quite uniform.

An opportunity to test Model C on a settler by modifying the feedwell did not occur because of operational constraints on settlers and washers preventing spare tank time availability for the modification to occur. There appeared to be a window of opportunity to modify the 47-metre diameter spare settler washer (which is used to replace settlers or washers when they are being cleaned) with a Model C feedwell before it went into washer service.

It should be noted here that the failure of a settler during normal operation might result in production loss whereas the failure of a washer increases costs by increasing soda loss. Therefore if the spare settler washer could handle two trains of feed in washer service instead of one then soda savings could be made.

Further CFD runs were carried out with Model C design but with liquor SG changed to reflect washer service. Encouraging results were obtained and simulation with two trains of feed also gave good results. In August 1996 the spare settler washer feedwell was modified and the capacity of the overflow and underflow piping upgraded to handle the extra flows. Two trains of residue were handled satisfactorily for three weeks in August/September 1996 before the tank had to be switched to other service. The results were so encouraging that even before the trial had been completed, CFD modelling on a 39-metre diameter washer had commenced.

Further modifications were required to the feedwell model to achieve satisfactory flow patterns. These were implemented on a 39-metre diameter tank in late September 1996. The tank was brought into service in early October 1996 and after extensive pump and pipe additions fed with two trains of residue (ie the residue from the total plant production) from mid November 1996. This tank was still operating satisfactorily with double feed in April 1997.

5.2 Washing Stages

The benefit of doubling the residue handling capacity of a 39 metre diameter tank is that it increases the washing stages in the CCD circuit and increases soda recovery. The refinery was designed with three washing stages in two trains. Worsley's present capacity expansion of 150,000 tonnes/annum, calls for the construction of a fourth washing stage. This feedwell innovation allows the fourth washing stage to be introduced 12 months early and at about a third of the construction cost.

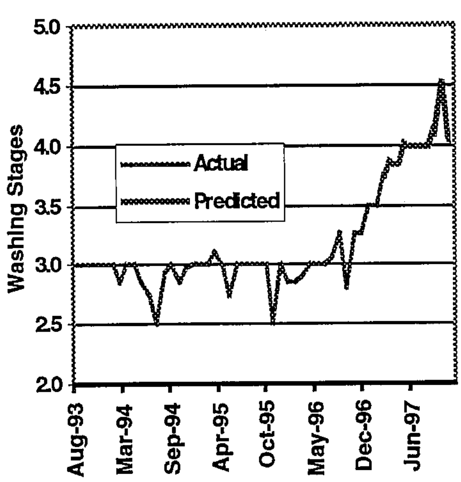


Figure 8 Washing Stages

Figure 8 shows the washing stages that have been in service over the last couple of years with the projection forward to 1998.

5.3 Future Benefits

Worsley is presently reviewing a design for doubling plant production with the CCD having four washing stages. This CFD modelling work and subsequent successful trials will reduce the number of new tanks required for this expansion by three and still maintain required end results.

6 FUTURE CFD PROJECTS

The settler and washer CFD modelling projects have been so successful that a number of other projects have been or will be initiated.

For example, CFD flow patterns of seed thickeners and the causticiser settler will be carried out to determine potential operational improvements.

7 CONCLUSIONS

Computational fluid dynamics (CFD) has been used to model fluid flow patterns in the feedwell in terms of time averaged velocity vector fields.

Validation of this model has been carried out by measuring the residence time distribution (RTD) of feed slurry in the feedwell by means of a lithium ion tracer technique.

The CFD modelling combined with field tracer studies and flocculant characterization has been instrumental in developing a better understanding of solid/ liquid/ flocculant feedwell behavior.

The information obtained was used for further CFD model developments and feedwell redesign which when implemented on plant equipment doubled residue handling capacity of the washers. This capacity increase has substantially reduced costs by increasing soda recovery.

The feedwell modification has reduced additional tanks required for expansions thus saving millions of dollars in capital.

ACKNOWLEDGMENTS

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