IMPROVING RED MUD FLOCCULATION AT AUGHINISH ALUMINA LIMITED

Peloquin, G.[1]*, Baxter, H.[2], Simard, G.[3], Kocaefe, D.[3] and Bui, R.T.[3]
[1] *Alcan International Limited, Arvida Research and Development Centre, Jonquière, Québec, Canada*
[2] *Aughinish Alumina Limited, Askeaton Co., Limerick, Republic of Ireland*
[3] *Université du Québec à Chicoutimi, Chicoutimi, Québec, Canada*

Abstract

Proper flocculation is essential in obtaining good performance of the liquor decanters and washers in the separation of red mud from liquor. The feed well is a key element helping to distribute and mix the flocculant with the incoming red mud slurry. At Aughinish Alumina Limited, the solid-liquid separation circuit is composed of six large diameter (41 m) thickeners operated in series. The ever-increasing mud load handled by the plant necessitated improvements in the efficiency of the circuit. A computational fluid dynamics (CFD) model of the operation of the feed well was developed to evaluate the performance of the existing feed well and the impact of modifications. The model simulates the two-phase flow of liquor and solid in the feed well. It is implemented in the commercial software CFX.

Several cases were simulated and the best configuration was selected to suggest modifications to the feed well. Initially, the feed well of a washer was modified in the spring of 2000. The modifications yielded a reduction in flocculant use, lowering of the settling interface and improvement in the underflow solids content. Subsequently, all feed wells have been, or will be modified as they become available. This paper describes the CFD model. It then details results of some of the cases run. Finally, the results observed in the plant with the modified feed wells are presented.

1. Introduction

Aughinish Alumina Limited (AAL) is an alumina refinery located in Ireland and producing 1.6 Mt/year of alumina. It mainly processes Boké bauxite in a high temperature digestion circuit. The separation and washing of red mud is done in wide body thickeners followed by rotary vacuum filters. The mud circuit is composed of two primary decanters and three washers.

In common with most alumina refineries during the last few years, AAL has set alumina production expansion objectives that require a mud circuit upgrade in order to process the additional tonnage of mud. One of these objectives is single decanter operation, converting the spare thickener to an additional wash stage. Moving more mud through the circuit translates to higher feed solids concentration and higher throughput in thickeners. This can only be done if settling rates and underflow solids are improved. Thus, the flocculation of the mud is critical in obtaining this improved performance. Since the feed well is a key element in achieving good flocculation, a systematic study on means to improve the efficiency of the feed well was started. The first washer was selected for this initial study since this poses the least risk of a process upset and its cycle time is short enough to allow the modifications to be implemented and evaluated quickly.

2. CFD model of feed well

In order to understand analytically the fluid flow in the feed well, a turbulent two-phase computational fluid dynamics (CFD) model of the entire thickener was developed in three dimensions. The first phase is continuous and represents the Bayer process liquor. The second phase is dispersed and represents the agglomerates of flocculated red mud. These two phases interact and there is momentum exchange caused by the solid drag force. There is neither chemical reaction nor mass transfer between the two phases. Settling of the solids under the action of gravity occurs because of the density difference between the two phases. The hindered settling caused by the high concentration of solids is taken into account in the model by using a suitable correlation. The viscosity of red mud suspensions is known to exhibit non-Newtonian behavior as the concentration of solids increases. This is also taken into account by expressing the liquid phase viscosity with a Hershell-Bulkley equation where the coefficients depend on the concentration of solids. The effect of turbulence is taken into account through the mixing length turbulence model, which captures the important behavior without adding unnecessary complication.

2.1 *Materials*

In the 1st washer, the Bayer liquor contains a moderate concentration of caustic soda and alumina. Its density is estimated to be 1134 kg/m^3. The red mud density is measured by pycnometer at 3200 kg/m^3. The agglomerates of red mud were measured by image analysis to establish their diameter and density [Peloquin et al., 2001]. Depending on the flocculant dosage selected, the diameter of the agglomerates varies. For this work, a diameter of 160×10^{-6} m is selected, corresponding to a free settling rate of 8 m/h as observed in the plant. The density of the agglomerates is estimated to be 1300 kg/m^3. Note that for this modeling work, all solids are assumed to be flocculated in the feed well. This constitutes a worst case scenario since the flocculated solids tend to settle more quickly than the fine unflocculated solids. The concentration of mud (solid) in the feed stream varies from 267 to 141 g/L of solids depending whether or not clear overflow is recirculated to the feed. Since the agglomerates of mud contain some liquor trapped within the solids, the concentrations are converted to solid volume fraction using the following relationship [Michaels et al., 1962]:

KEY WORDS: feed well, flocculation, CFD, modeling

$$r = \frac{C_m}{\rho_m}\left(\frac{\rho_m - \rho_l}{\rho_s - \rho_l}\right) \quad (1)$$

where r_s is the volume fraction of solid, C_m is the concentration of mud in g/L, ρ_m, ρ_l and ρ_s are respectively the density of red mud, liquor and agglomerates of mud.

2.2 *Equations*

The conservation equations to be solved are the momentum transfer equations for both phases and the volume fraction equation. The drag coefficient C_D expresses the momentum exchange between the solid and liquid phases. Standard correlations are used depending on the Reynolds number (*Re*); for 0< *Re* < 0.2, Stokes law $C_D = 24/Re$ is used; for 0.2 < *Re* < 1000, Ishii-Zuber correlation [Ishii et al., 1979] $C_D = 24\,(1 + 0.1\,Re^{0.75})/Re$ is used. If the concentration of solid is high enough, the mutual interaction of these solid particles needs to be taken into account as they hinder the free settling. The Ergun equation is used for the inter-phase drag term [AEA Technology]:

$$c_{ls} = 150\frac{(1-r_l)^2\mu_l}{r_l d^2} + 1.75\frac{(1-r_l)\rho_l\left|U_s - U_l\right|}{d} \quad (2)$$

where subscripts l, s stand respectively for the liquid and solid phase, *r* is the volume fraction, *d* is the diameter of the solid particles, μ is the viscosity of the liquid phase, ρ is the density and *U* is the velocity vector.

The viscosity of a red mud suspension exhibits a non-Newtonian behavior as the concentration of solid increases. The phenomenological Hershell-Bulkley model describes this behavior well. The viscosity of the liquid phase is calculated with the following equation derived from measurement of the properties of red mud suspensions at several concentrations of solid by rotational viscosimetry.

$$\mu_t = \frac{c_1\exp(c_2 r_s) - c_3 + c_4\exp(c_5 r_s)\gamma\left(c_6 + \frac{c_7}{r_s + c_8}\right)}{\gamma} \quad (3)$$

where c_1, …, c_8 are phenomenological constants, r_s is the solid volume fraction and γ is the shear rate.

Typical feed velocity of the slurry is 1.7 m/s, in a 0.3 m diameter pipe. This translates into a Reynolds number of around 400 000. The simple mixing length turbulence model [White, F.M., 1991] is used to compute the turbulent viscosity of the liquid μ_t, according to equation (4), where ρ_l is the density of the liquid, κ is the Von Karman constant (0.41), *l* is the mixing length constant set to the average diameter of the feed pipe 0.3 m, and *d* is the rate of strain tensor. Equation (4) expresses that the turbulent viscosity is proportional to the local velocity gradient. This turbulent viscosity component is added to the laminar viscosity of the liquid phase at each iteration.

$$\mu_t = \rho_l \kappa l^2 [trace(\underline{\underline{d}}\,\underline{\underline{d}})]^{1/2} \quad (4)$$

2.3 *Geometry and boundary conditions*

The thickener is a 41 m diameter flat bottom tank. The height of the wall is 5 m. There is a 6 m diameter by 1.9 m high feed well at the center of the tank. The feed well is attached to the rake drive mechanism and rotates with the rake. Feed enters the tank through a 0.3 m diameter feed pipe tangential to the feed well wall. The feed pipe does not run through the feed well wall but instead enters the feed well from the top. Nominal feed flow is 450 m^3/h at 267 g/L solids. There is a 1.5 m diameter concrete support column in the center of the feed well. There is one annular underflow outlet at the bottom of the tank near the support column. The liquor overflows from a weir around the circumference of the thickener. In the model, the feed is an inlet while the underflow and overflow are outlets with the appropriate velocity magnitudes. The feed well is modeled by imposing a thin solid surface inside the domain.

2.4 *Grid*

A multi-block grid composed of 26 blocks and 37400 cells is used. The grid is illustrated in Figure 1 along with the inlet (feed), outlets (overflow and underflow) and the feed well.

2.5 *Solution*

Solving the equations is carried out with CFX 4.3 commercial code, from AEA Technology using the finite volume technique. The two-phase momentum transfer equations are solved with the IPSA algorithm. A transient simulation is carried out with varying time steps for 6000 seconds of problem time. A typical case takes about 12 hours to converge on a Pentium III 866 MHz, under Windows NT. It was decided to approach steady state through a transient simulation in order to improve convergence.

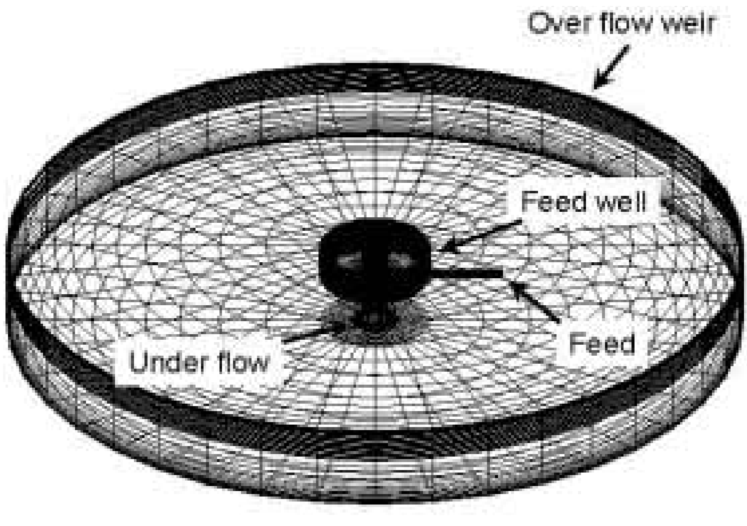

Figure 1 — Grid for the CFD model of the 1st washer at Aughinish

3. Results

Several simulations were done to study the effect of modifications to the feed well. In order to interpret the data, we must first consider the role of the feed well with regards to flocculation of the mud. Usually, flocculant is added in the feed well. Some of it can also be added to the feed pipe prior to reaching the feed well. In both cases, sufficient agitation is needed to promote contact between the mud and the flocculant. Furthermore, the internal dilution provided by the feed well lowers the solid concentration and thus facilitates flocculation of the mud. On the other hand, if the agitation level is too high, breakage of the agglomerated mud can occur leading to degradation of performance [Gagnon et al., 2002]. It follows that the key factors in evaluating the performance of the feed well are the velocity vector field, the solid concentration distribution and the calculated internal dilution. The liquid vector fields will be presented first for the cases simulated. A discussion of the results will follow with a graph and a table comparing all cases.

3.1 *Base case*

Firstly, the original thickener configuration was simulated to establish the base case. Figure 2 presents the liquid phase vector field in the feed well and in the area close to it, for a vertical plane at 90° from the feed inlet. We can see that there is some vertical movement in the feed well. The swirling motion caused by the velocity of the feed draws some liquid from the bulk of the washer. This is called internal dilution and reduces the solid concentration in the feed well and promotes better flocculation. However, because the feed pipe is close to the wall, a significant amount of liquid hits the wall and is deflected towards the bottom of the washer at a high velocity. This leads to short-circuiting in the feed well and makes it less homogeneous. It is detrimental to flocculation. Furthermore, this downward stream has the potential to re-suspend some mud in the bed, thus reducing the underflow solid concentration and bringing settled mud back in the feed well.

3.2 *Feed pipe integrated with the feed well wall*

Figure 3 shows the vector field for the same plane as Figure 2, for the case where the feed pipe is integrated with the wall of the feed well. Instead of entering from the top of the feed well, the feed pipe passes through the wall tangentially. The vectors are very similar to those for the base case (Figure 2). In fact, there is no benefit integrating the pipe with the wall. The main flow features are not dependent on the detailed arrangement of the feed pipe as long as it remains tangential to the wall of the feed well.

3.3 *Annular ring*

The addition of an annular ring at the base of the feed well was simulated next. Figure 4 presents the liquid vector field for the same plane as in Figure 2. It can be observed that the ring eliminates the downward moving liquid stream close to the wall. Because of the ring, it is deflected towards the center of the feed well and promotes a better mixing. Also, the velocities near the mud bed are smaller, reducing the interference with the settled mud.

3.4 *Annular ring and overflow recirculation*

The effect of the annular ring and an external overflow recirculation of 400 m^3/h was then simulated. This is accomplished in the plant by installing a pump that circulates clear overflow back to the feed, thus reducing the solid concentration in the feed pipe while increasing the flow rate. Figure 5 shows the liquid vector field. We can see that there is more movement in the feed well. This could lead to higher breakage of the agglomerated mud particles compared to the previous case. The movement at the base of the feed well is also important. Again, the potential for interference with the mud bed exists. From the vector field only, it is difficult to establish if the overflow recirculation is beneficial. However, since it is usually independent of variations in the feed flow rate, it might be advantageous to implement it for control reasons.

4. Discussion

To complement the qualitative interpretation of the data calculated earlier, some quantitative analysis is presented in Table 1 where the liquid internal dilution ratio and the solids dilution ratio are listed for all cases simulated. The liquid internal dilution ratio is computed by integrating the upward liquor flow rate for a plane located at the bottom of the feed well and dividing it by the liquid feed flow rate. It

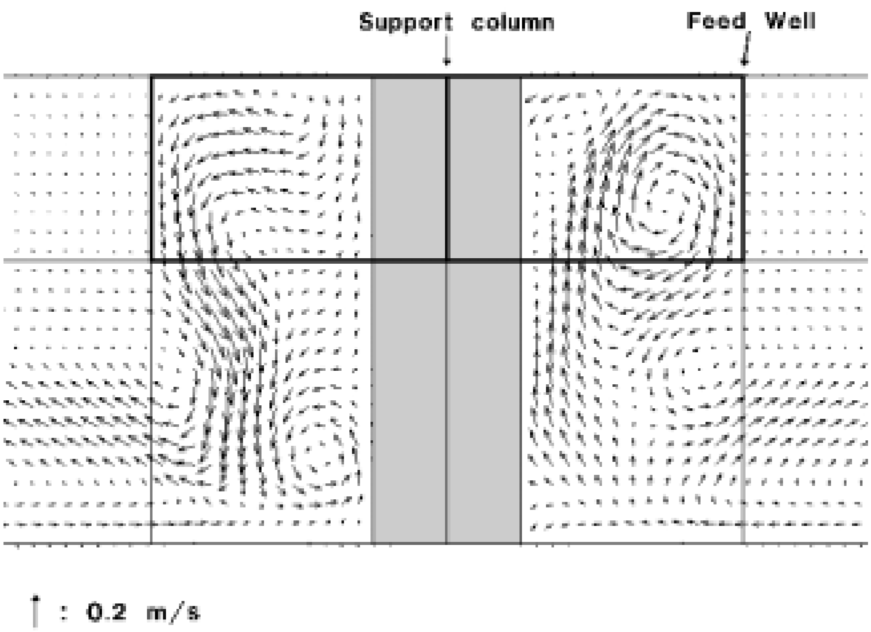

Figure 2 — Liquid vector field in the feed well area, for the simulation of the base case, for the 1st washer at Aughinish

expresses the amount of dilution liquor with respect to the feed liquor. The solids dilution ratio is calculated as the ratio of the feed solid volume fraction to the volume average of the solid volume fraction for the entire volume of the feed well. It also expresses the feed well feed solids dilution efficiency, while taking into account the solids that can be brought back in the feed well through a plane at its bottom. A large solids dilution ratio indicates that the feed solids are well diluted in the feed well. Note that for the case with the external recirculation, the combined effect of internal and external recirculation is reported in Table 1.

From Table 1, it can be noted that a simple feed well dilutes the solids by a factor close to 2. We can see that integrating the feed pipe with the feed well wall does not significantly change the dilution ratios compared to the base case. We can also see that adding an annular ring severely reduces the liquid internal dilution but does improve the solids dilution ratio. This is explained by the elimination of the downward stream interfering with the mud bed when the annular ring is installed, as detailed earlier. It is also noted that adding the external recirculation gives an additional improvement to the dilution of solids.

Table 1 — Liquid internal dilution ratio and solids dilution ratio for all cases simulated

Case	Liquid internal dilution ratio	Solids dilution ratio
Base	6.95	1.85
Feed pipe integrated with the wall	8.76	1.96
Annular ring	2.11	2.70
Annular ring and recirculation	3.42	4.55

To characterize the agitation and the homogeneity of the feed well, the distribution of solid concentration in the feed well was also computed. The results are presented in

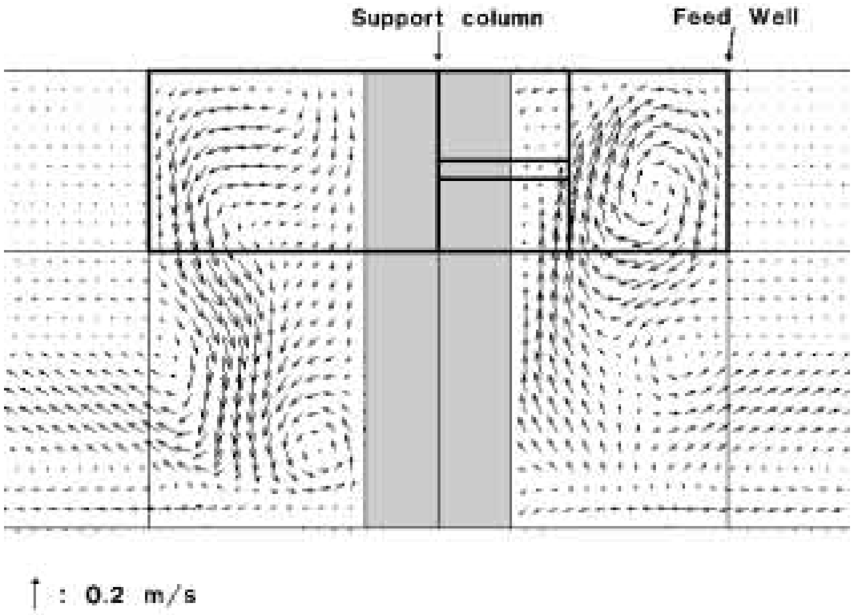

Figure 3 — Liquid vector field in the feed well area, for the simulation of the feed pipe integrated with the wall of the feed well, for the 1st washer at Aughinish

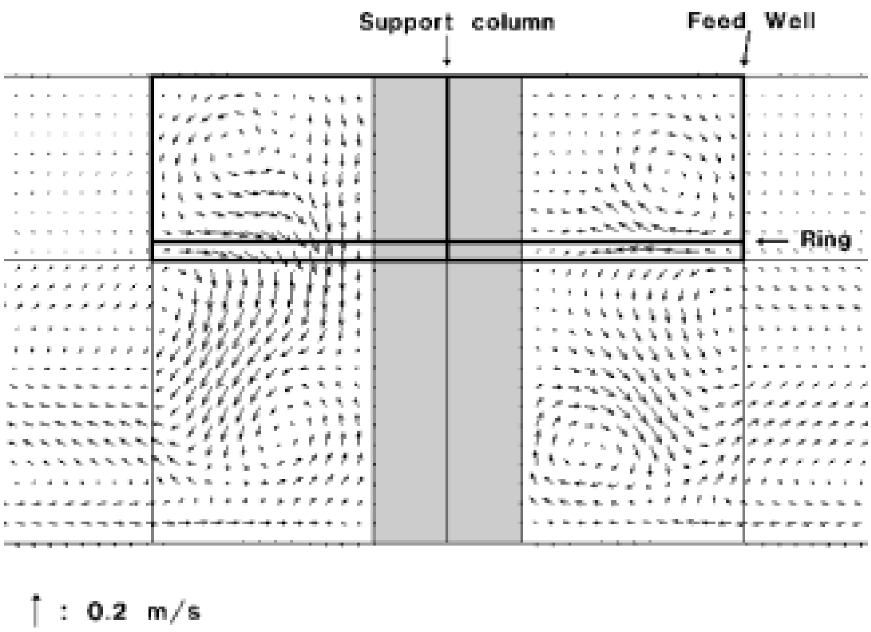

Figure 4 — Liquid vector field in the feed well area, for the simulation of the effect of an annular ring, for the 1st washer at Aughinish

Figure 6 where the percentage of the volume of the feed well corresponding to each solid concentration is plotted. It gives an estimate of how well the solids are distributed in the feed well. It can be seen that for the base case and for the case of the feed pipe integrated with the wall, results are very similar. There is a large variation of concentration in the feed well with solids ranging from 50 g/L to about 250 g/L. This indicates poor homogeneity and poor action of the feed well. The installation of the annular ring drastically changes the concentration profile. The feed well is significantly more homogeneous with most of the volume at 75 to 100 g/L solid. The addition of the external recirculation slightly changes the solids profile by shifting the concentration to lower solids and by widening the distribution. These last two cases indicate improved performance of the feed well.

5. Plant results

Considering the results of the simulations, it was decided to modify the feed well of the 1st washer by adding an annular ring at its base. Depending on the observed performance, the overflow recirculation could be added later if needed. The washer was put back on service in the spring of 2000. A lowering of the settling mud interface was immediately noticed along with an improvement in the response of the position of this interface with flocculant dosage. Over the months, the gain in performance was repeatedly tested with higher tonnage of mud (35% more mud) and higher feed flow rate (45% higher flow rate) pumped to the washer without loss of control of flocculation or settling. By informally sampling through access holes on top of the thickener, circulation in the feed well

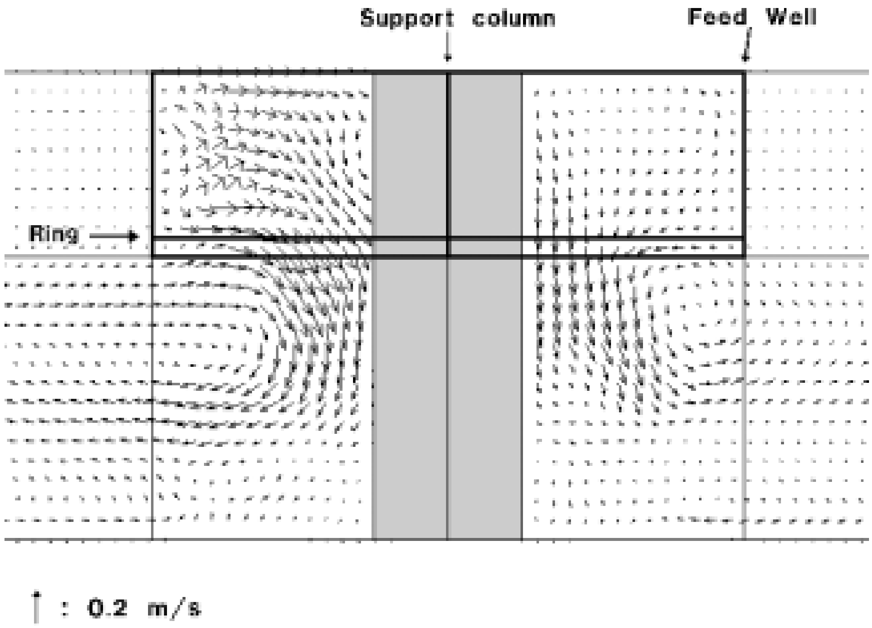

Figure 5 — Liquid vector field in the feed well area, for the simulation of the effect of an annular ring and overflow recirculation, for the 1st washer at Aughinish

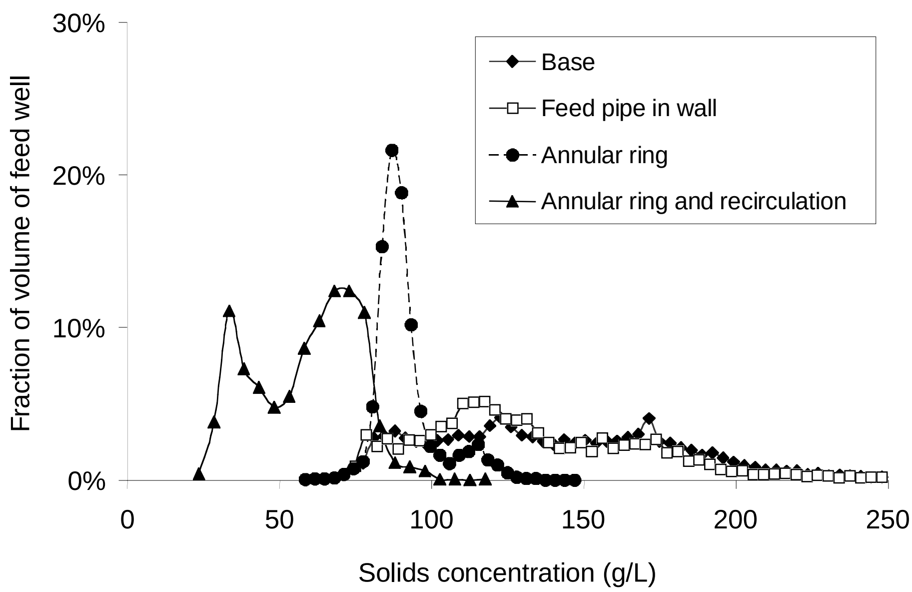

Figure 6 — Distribution of solid concentration in the feed well for the cases simulated, for the 1st washer at Aughinish

was found to be improved and flocculation more uniform. It was also noted that underflow solids increased by 1.5% to 2.0% after the installation of the annular ring. This significant gain translates to improved washing efficiency in the mud circuit and reduced soda losses. This improvement in underflow solids is caused by better flocculation of the mud and also by the elimination of the downward stream of liquor along the wall of the feed well, as discussed earlier.

Because of the good results obtained with the 1st washer, the feed wells of all washers have been, or will be modified with the installation of an annular ring. A study of the fluid movement in the primary decanters was also started to see if the same benefits could be obtained for these vessels. The same modification is not straightforward because of the important difference in feed flow rates and feed pipe arrangements when comparing primary decanters to washers. Furthermore, the requirements of the two services are different.

6. Conclusion

The application of CFD simulations to fluid flow in feed wells of thickeners in the Bayer process has proven to be successful. Improvements in flocculation and compaction were seen following modifications to the feed well based on CFD results.

The simulations have also avoided costly and unnecessary modifications to the feed well. Prior to seeing the simulation results, the plant engineers believed that an integrated tangential entry to the feed well was necessary before any improvement in performance could be realized. The CFD simulations proved this option to be unnecessary.

CFD simulation is an additional tool for the understanding of fluid flow in feed well and vessels. Complemented with observations and with the experience of operators and engineers, it can help in making more informed and less risky modifications to the geometry of the thickeners in the Bayer process. However, some experience is required to apply CFD data to the plant situation with optimum efficiency.

Acknowledgements

The collaboration of Claude Boulanger and Jacques Laurier from Alcan, and Andrew Furlong and Ed Lowe from AAL was greatly appreciated.

References

AEA Technology, CFX 4.2 Solver Manual.

Gagnon, M.J., Simard, G., Normandin, M. and Peloquin, G., Behavior of red mud agglomerated with various flocculants under shear conditions, Light Metals 2002, 107–114.

Ishii, M. and Zuber, N., Drag coefficient and relative velocity in bubbly, droplet or particulate flows, AIChE Journal, 25 (5), 1979.

Michaels, A.S. and Bolger, J.C., Settling rates and sediment volumes of flocculated kaolin suspensions, I&EC Fundamentals, 1 (1), February 1962.

Peloquin, G., Bui, R.T., Kocaefe, D. and Simard, G., CFD simulation of red mud settling in a laboratory scale decanter, Proceedings of the 9th Annual conference of the CFD Society of Canada, May 2001, 289–294.

White, F.M., Viscous Fluid Flow, McGraw Hill, 2nd edition, 1991.