CFD MODELLING OF A RAPIDORR 444 CLARIFIER: RECENT PROGRESS

S CHETTY AND SB DAVIS

Sugar Milling Research Institute, University of Natal, Durban, 4041, South Africa

Abstract

Past Computational Fluid Dynamics(CFD) work on the Rapidorr 444 required a quantitative check of its accuracy. Factory tracer tests were used to validate the developed CFD model. Since the model was a function of its input, these parameters, particularly juice and mud densities were re-calculated over an entire season and average values used. In addition a new three-dimensional model of the Rapidorr clarifier was created offering improved accuracy and presentation of results but at the sacrifice of increased computation time. Hence this model was used sparingly. Possible structural modifications were tested and evaluated in terms of the diameter of the smallest particle that settled out and the change in juice residence time. A combination of a deflector baffle mounted directly in the path of the inlet flow and a baffle mounted on the scraper arms lead to a quantitative improvement in mud settling at the sacrifice of increased residence time. However, the residence time could be restored either by flow manipulation or further structural modification. The modifications also lead to improved robustness of the Rapidorr at low mud densities.

Keywords: clarifier rapidorr, carry-over

Introduction

Steindl *et al*. (1998) reported modifications to the SRI clarifier based on CFD modelling that reduced juice residence times in the SRI clarifier, without sacrificing clear juice quality. In light of this advancement, the SMRI started a CFD project in 1998 around the Rapidorr 444 clarifier. The first output published by Peacock *et al*. (2000) gave insights into flow patterns in the Rapidorr and an evaluation of structural modifications in terms of particle settling. However, the model that was developed was not validated. In addition there were aspects of the geometry that were neglected. Therefore it was decided to validate the current model and develop a more complex model to characterize the system.

CFD input parameters

CFD modelling is dependent on its input and model formulation. The crucial input parameters to the CFD model were the material properties of mud and to a lesser extent mixed juice, and throughputs. These properties vary seasonally, hence average values computed from weekly factory figures were used in the model. Seasonal variations were also looked at since the data was available. Mixed juice density and viscosity were mainly dependent on Brix and hence increased from the start of the season and decreased towards the end of the season. Detailed calculations and results are discussed by Chetty (2000). Of paramount importance was the density driving force for mud settling, i.e. the difference between mud density and juice density. Two methods were employed for the calculation of mud density viz: the method of Nix (1972) which was dependent on mixed juice suspended solids and mixed juice density, and a fundamentalist approach using published settling rates (Lionnet and Ravno, 1976) and estimated particle sizes and sphericities from microscopic examination of mud samples from Maidstone. The results from the former, with a published accuracy of 0.04% (Nix, 1972), are shown in Figure 1. A good agreement was achieved between the two methods. The effects of the variation of the driving force are discussed at a later stage in the report.

Validation of CFD models

Matko *et al*. (1996), Steindl *et al*. (1998) and Szalai *et al*. (1994) have successfully validated CFD models via tracer testing. Factory tracer tests were performed on Maidstone No. 2 clarifier with details of the results presented by Naidoo (2000). The tracer tests were then simulated via the CFD models by specifying the inlet tracer concentrations and operating conditions. The major problem was determining the correct inlet flow to the compartment being modelled. This was accomplished by using the average residence time for each compartment determined from the factory tracer tests. For the test by Naidoo (2000) the second compartment had a flow equal to one quarter of the total flow to the clarifier, hence no velocity adjustment was needed. Although no on-line measuring of total flow was used, control room readings were noted when the flow was changed. The result of the test is shown in Figure 2 where an adequate fit was realized. However, it must be borne in mind that the comparison is subject to the following sources of error:

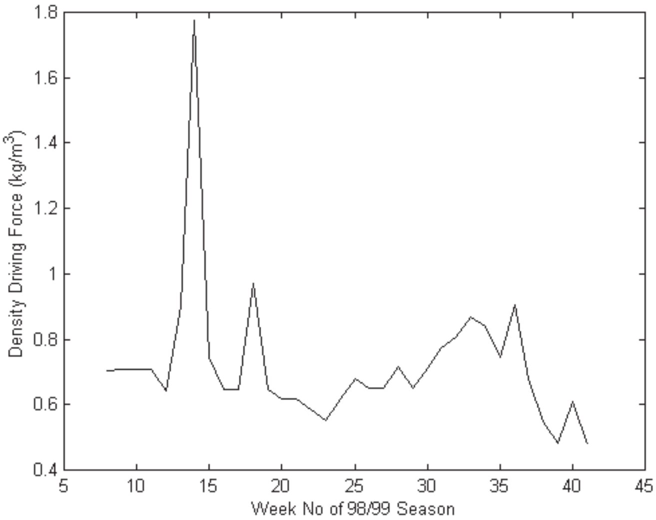

Figure 1. Seasonal variation of density driving force.

- Salt density was assumed to be equal to juice density.
- Mud phase was only modelled as solid particle injection rather than a separate phase within the clarifier.

Model development

The use of an axi-symmetric (two-dimensional) model allows only for circumferentially continuous inlets and outlets. The use of a single continuous inlet or outlet to simulate circumferentially discontinuous openings has been successfully employed by Harris *et al* (1995) for a crystalliser and Steindl (1995) for the SRI clarifier. Laine *et al* (1999) modelled a flocculator-settling tank using a two-dimensional slice. Szalai *et al*. (1994) also employed this strategy for a circular clarifier but recommend true three-dimensional modelling of the inlet structure and incorporation of swirling scrapers present in the structure. Hence a three dimensional model was developed employing swirling scrapers, and discontinuous inlets and outlets. The model offered marginally higher accuracy as seen in Figure 2 but was used sparingly for the following reasons.

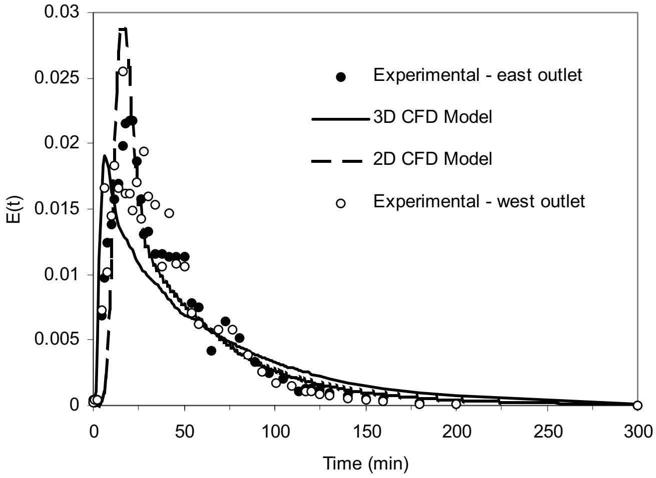

Figure 2. Residence Time Distribution (RTD) curves from simulated and factory tracer tests.

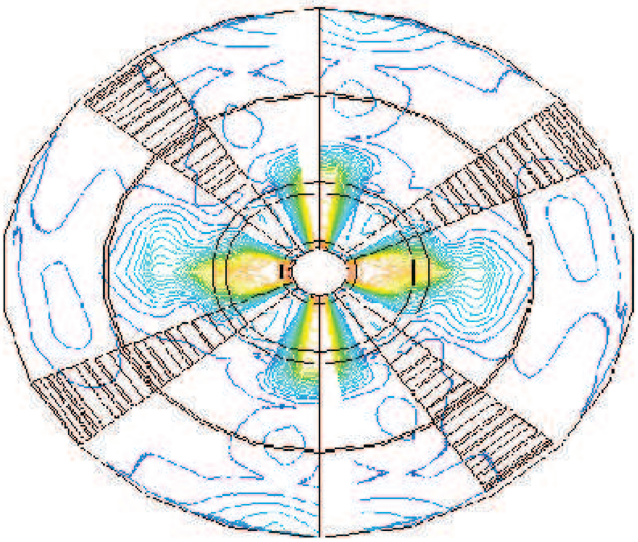

Figure 3. A slice through the clarifier at the level of the feed horns showing inlet plumes.

- Computation time was of the order of days compared to the axi-symmetric model, which only took an hour to converge.
- The number of cells in the tangential direction between inlet horns, and between outlet slots was limited by computer memory. As advised by Bakker *et al*. (2001) this could lead to erroneous results.
- Results from the 3D model showed that in spite of dispersion from the feed horns shown in Figure 3, the 2D model was an adequate representation of the clarifier (Chetty and Davis, 2001).

Structural modifications

Modifications via CFD modelling on the SRI clarifier have shown a 60% reduction in juice residence time (Steindl *et al*, 1998) by increasing the outlet area in a particular fashion (Steindl, 1995), although the reported modifications do not change the clarifier's sensitivity to flow fluctuations (Jullienne and Montocchio, 1996). Additional outlet area in the form of an additional outlet pipe was tested using CFD but lead to poor mud settling. Typically, modifications to the Rapidorr 444 have focussed more on attaining circumferentially even flow. Van Duyker *et al.* (1986) modified the outlet system to include more offtake points linked to a baffled annular collection box leading to an improvement in capacity. Scott (1988) reported modifications to the outlet system where two semi-circular outlet pipes were used with equally spaced off-take holes in them. Scott (1988) also makes mention of a horizontal baffle at the feed entry which is now termed a feed baffle. The modifications allowed a juice residence time of about an hour. The latest tracer tests on the Maidstone Rapidorr 444 revealed that the average residence time was 40-50 minutes (Naidoo, 2000).

Single baffles tested showed no improvement in mud settling even at varied operating capacity. Angling of the feed baffle and removing the feed baffle were tested to reduce the residence time. In spite of producing early peaks in residence time distribution curves, no improvement in residence time was achieved. Adding a second outlet pipe caused excessive carry-over due to changing the flow patterns. Improvements in mud settling were achieved by using two 100 mm high baffles viz: one mounted on the scraper arms and another close to the feed inlet. The idea was that a reduction of inlet momentum would cause the mud particles to settle out closer to the mud boot. Mud settling for the base case and the modified case are shown in Figures 4 and 5 respectively.

In addition to settling out the 0.41 mm particle, it is clearly evident that the mud settles out closer to the mud boot due to the modification. It is also clear from Figure 5 that the baffle mounted on the scraper arm has a direct effect on the 1 mm diameter mud particle which was identified as the 'small individual particle' by Steindl *et al*. (1998). The quantitative improvement in the smallest particle that settles out (Dp_{min}) is shown in Figure 6 at varying residence times. The effective space times shown in Figure 6 were calculated as the ratio of effective clarifier volume to volumetric juice flow. The effective space time was equal to the average residence time at nominal flowrates.

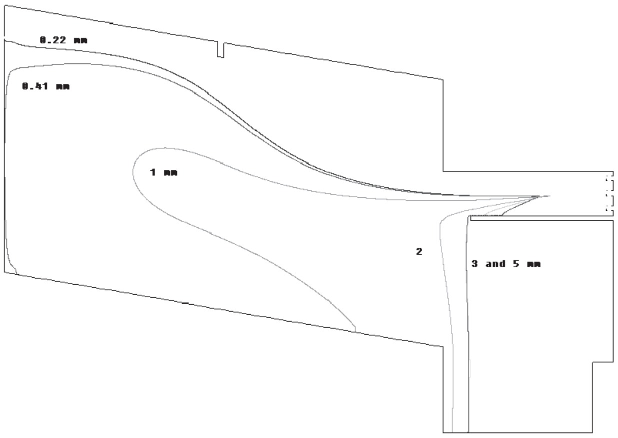

Figure 4. Mud settling for the base case at 247 tons mixed juice/hour.

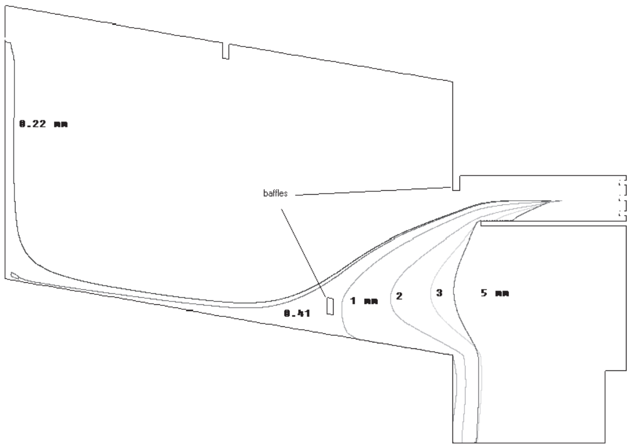

Figure 5. Mud settling for the modified clarifier at 247 tons mixed juice/hr.

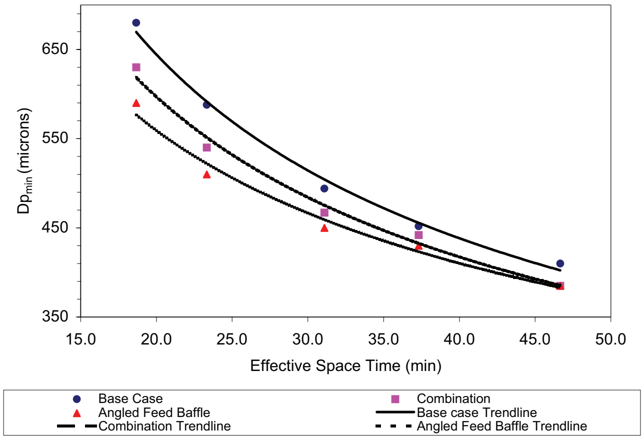

Figure 6. Mud settling at varied throughputs for base and modified cases.

Tracer tests were then simulated to determine average residence times for the base case and modified Rapidorr at nominal flowrates. The results are shown in Figure 7. It was determined that although the angled feed baffle produced an early peak, it had a negative effect on residence time. The combination baffles caused a 15% increase in residence time. This could be negated by increasing the flow through the modified clarifier since it would be less susceptible to long term flow variations as shown in Figure 6. In the event that it was not possible to increase the flow to decrease the residence time, an additional outlet pipe mounted next to the ceiling stiffener would cause an improvement to the average residence time bringing it closer to the base case, at no expense of clear juice quality. The RTD curve for the combination baffles and an additional outlet pipe are shown in Figure 7. Flow patterns for the base case, modified with combinational baffles and extra outlet pipe are discussed in the Appendix. The additional outlet pipe did not affect mud settling, in fact there were some beneficial effects as shown in Figure 8.

Seasonal fluctuations in density driving force (the difference between mud density and juice density) shown in Figure 1 were fed into the CFD model. The results are shown in Figure 8. It is clearly evident that an improvement in robustness would be achieved by implementing the baffles. It must be noted that the average density driving force was calculated as 0.7 kg/m^3 whereas the density driving force used to calculate values in Figure 6 was 0.9 kg/m^3. Hence results from Figure 6 only have a relative rather than absolute value. Carry-over would be greater at high throughputs with lower density driving forces. A study of the combinational effects of driving force and throughput was not completed but is a possible direction of future work.

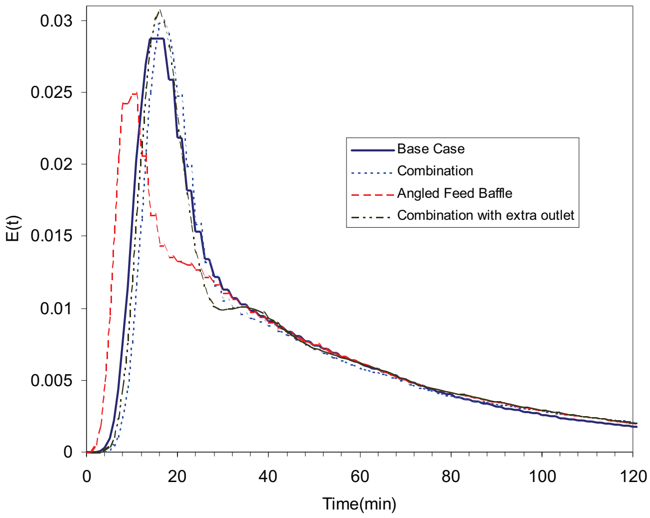

Figure 7. RTD curves for base case and modified clarifier.

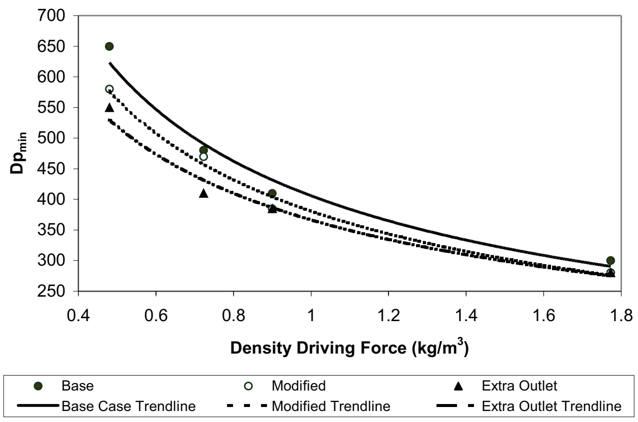

Figure 8. Mud settling at varying density driving forces.

Conclusion

Modifications to a Rapidorr clarifier have been tested via CFD modelling after successful validation. It was determined that a combination of two 100 mm high baffles, one near the inlet and one mounted on the scraper arm, would cause an improvement in mud settling, at the sacrifice of increased residence time. The residence time can be restored by either increasing throughput since the modified clarifier would be more robust or by installing an additional outlet pipe.

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REFERENCES

Bakker, A, Haidari, AH, and Oshinowo, ML (2001). Realize greater benefits from CFD, *Chem Eng Prog,* March 2001, pp 45-53.

Chetty, S (2000). Validation of two-dimensional Computational Fluid Dynamics (CFD) model of a clarifier, *Sugar Milling Research Institute Technical Report 1838*, 8 October 2000.

Chetty, S and Davis, SB, (2001). 2nd CFD modelling progress report , *Sugar Milling Research Institute Technical Note 11/01*, 17 May 2001.

van Duyker, W, Tosio, C, and Lung Kit, H (1986). Modifications to and uprating of clarification station at Simunye, *Proc S Afr Sug Technol Ass* 60: 40-42.

Harris, JA, Robinson, JA, and Vigh, S (1995). Mathematical modelling of flow and heat transfer in a vertical crystalliser, *Proc Aust Soc Sugar Cane Technol* 70: 216-221.

Jullienne, LMSA and Montocchio, G (1996). Review on design and operation of clarifiers in the South African sugar industry for the period 1975 to 1995, *Proc S Afr Sug Technol Ass* 70: 277-279.

Laine, S, PhanL, Pellarin, P, and Robert, P (1999). Operating diagnostics on a flocculator-settling tank using Fluent CFD software, *Wat Sci Tech* , Vol. 39, No. 4, pp. 155-162.

Lionnet, GRE, and Ravno, AB (1976). Flocculant assessment using a portable batch settling kit, *Proc S Afr Sug Technol Ass* 50*:* 176-178.

Matko, T, Fawcett, N, Sharp, A, and Stephenson, T (1996). A numerical model of flow in circular sedimentation tanks, *Tans IchemE*, Vol 74, Part B, August 1996, pp 197-204.

Naidoo, L, (2000). Results of an early season tracer test on Maidstone clarifier 2, *Sugar Milling Research Institute Technical Note* 16/00, 1 November 2000.

Nix, KJ (1972). The density of primary mud. *Proc Queensland Soc Sugar Cane Technol* 39 : 281-287.

Peacock, SD, Davis, SB, Govender, KA, Moodley, K and Brouckaert, CJ (2000). Computational Fluid Dynamics modelling of a Rapidorr 444 clarifier, *Proc S Afr Sug Technol Ass* 74: 348-353.

Scott, RP (1988). Modifications to and experiences with Rapidorr clarifiers including saccharate liming at Amatikulu, *Proc S Afr Sug Technol Ass* 62: 32-35.

Steindl, RJ, (1995). Optimum performance through CFD modelling of clarifier designs, *Proc Aust Soc Sug Cane Technol* 17: 207-215.

Steindl, RL, Fitzmaurice, AL, and Alman CW (1998). Recent developments in clarifier design, *Proc Aust Soc Sugar Cane Technol* 20: 477-483.

Szalai, L, Krebs, P, and Rodi, W, (1994). Simulation of flow in circular clarifiers with and without swirl, *Journal of Hydraulic Engineering*, ASCE, Vol. 120, No. 1, pp 4-21.

Appendix : Clarifier flow patterns

The following figures show the flow patterns in the Rapidorr 444 compartment before and after structural modifications. Figure 9 shows the unmodified case. The juice enters the compartment and is directed by the feed baffle towards the outlet. The stream reaches the outlet where much of it is diverted due to congestion of flow at the outlet. The diverted stream flows towards the inlet where it's direction is reversed by the relatively fast moving inlet stream. The constant diversion of flow causes a large region of re-circulation to exist from the floor towards the roof where it meets the juice stream flowing towards the outlet that eventually exits the compartment.

Figure 10 shows the flow patterns for the modified case of two baffles. Here the inlet flow is directed towards the floor causing the large region of re-circulation in Figure 8 to split into two smaller regions. The second baffle causes a small region of re-circulation near the mud boot. The region causes the mud to settle closer to the mud boot. Figure 10 shows flow patterns with an extra outlet in addition to the two baffles. The only difference is that some of the flow that is diverted from the first outlet goes out through the second outlet, rather than contribute towards the re-circulation region. The additional exit area serves to reduce the average juice residence time.

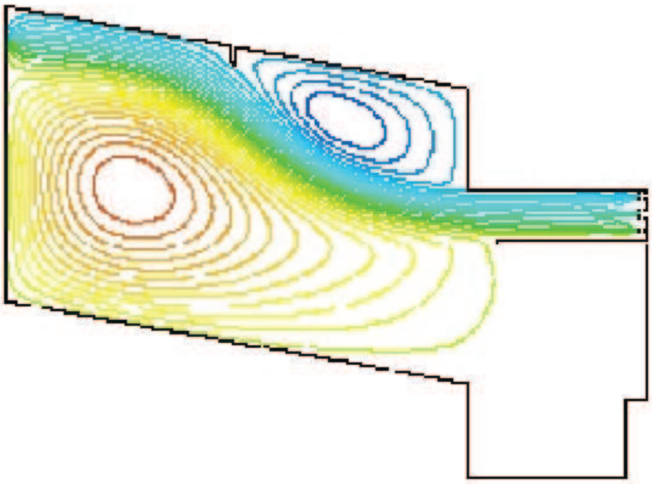

Figure 9. Base case streamlines for the Rapidorr 444.

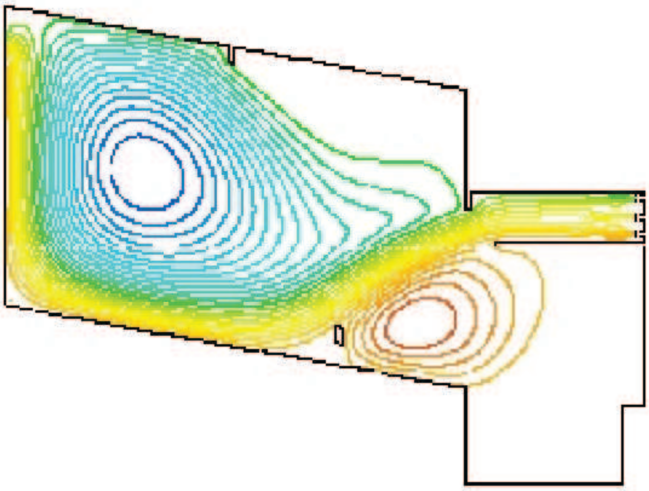

Figure 10. Streamlines for the combination baffles.

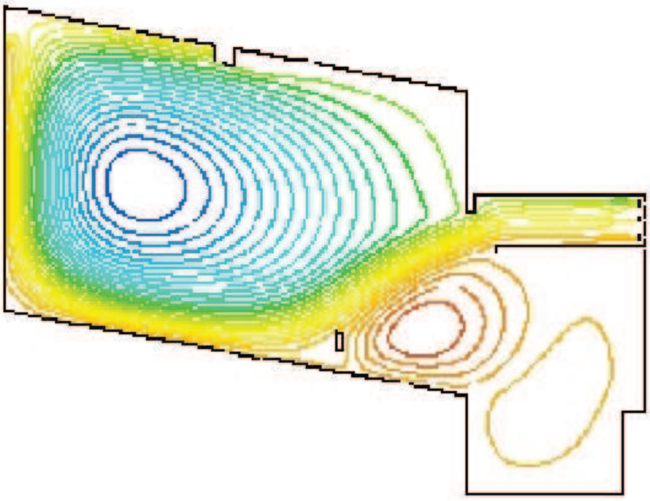

Figure 11. Streamlines for combination baffles and additional outlet pipe.