OPTIMUM PERFORMANCE THROUGH CFD MODELLING OF THE SRI CLARIFIER DESIGN

RJ STEINDL

Sugar Research Institute, Mackay, Queensland, Australia.

Abstract

The concept of computational fluid dynamics modelling is introduced and potential applications within the sugar industry are identified. The availability of the computational fluid dynamics package FIDAP has enabled an analysis of the flows occurring in a SRI clarifier to be undertaken. The results of a number of simulations indicate the predicted flows are in general agreement with those that have been observed in factory installations. The model predictions have emphasised the importance of achieving high settling rates with large flocculated mud particles. The availability of FIDAP and the clarifier models permit the effects of changes to operational strategies and mud settling characteristics to be examined. Results are presented using the modified SRI clarifier design for Eston mill to demonstrate the advantages of being able to investigate design modifications before the design is manufactured.

Introduction

The use of computational fluid dynamics (CFD) is rapidly being established in many industries as a pivotal stage in improving performance in processes involving heat transfer and fluid flow. It is a powerful tool for the refinement of existing equipment and for problem resolution. CFD models enable a detailed examination of the fluid flow regime, something that is not normally available from experimental techniques. Because CFD models do not involve real plant items and fluids, the models are cheap and safe to run and, once the model has been fully developed, variations in design or process conditions can be examined without expensive plant modifications.

Potential applications within the sugar industry include:

- particle trajectory simulations such as the dispersal of bagasse dust, dispersal of plumes from boiler stacks, and mud settling in a clarifier
- furnace modelling of bagasse combustion
- the interaction between cane billets and trash during pneumatic separation
- the simulation of flow of non-Newtonian fluids such as molasses, massecuites and oils
- the simulation of flows over irregular or curved surfaces such as boiler tubes or the blades of an induced draft fan
- the simulation of two-phase flow in pans, evaporators, and entrainment separators
- environmental considerations such as the dispersal of hot injection water into rivers and streams, circulation of effluent in ponds and distribution of introduced air in aeration ponds.

Previous studies by SRI of the flow patterns in process vessels have been based on experimental tracer tests and residence time distribution analyses (eg using dye or lithium tracer studies). However, these techniques are of limited value in determining flow patterns at specific locations within the vessels. CFD modelling allows such problem areas to be explored.

CFD techniques have been used in other areas of interest to the sugar industry. Improvements are anticipated in pneumatic cane cleaning on billet cane harvesters from one such study. The more specialised CFD code FURNACE has also been used extensively to study bagasse combustion in sugar mill boilers (Dixon and Plaza, 1995a) and erosion in boiler tube banks (Dixon and Plaza, 1995b).

Design studies of the SRI clarifier

The prototype SRI trayless clarifier installed at Gin Gin sugar mill in 1969 (Hale and Whayman, 1970) represented a major advance in clarification technology for the Australian cane sugar industry. That unit was 6,1 m in diameter and was designed for a cane crushing rate of 120 t/h. The average initial settling rates of flocculated mud at the time were 20 cm/min. Since then, the SRI clarifier has been widely adopted throughout the cane sugar world.

The clarifier has proven its versatility in being able to handle a wide range of flow rates and mud loadings. This versatility has created a problem in specifying the upper limit of throughput for a given size clarifier in that the limit cannot be uniquely defined.

The SRI clarifier design

A sectional view of a standard SRI clarifier is shown in Figure 1. The principle of the design was the concept of introducing feed through a 'multiplicity of openings' and withdrawing overflow over the entire surface area. This was to be achieved with a minimum retention time. While the concept was not new, the SRI clarifier came closest to achieving the ideal. Sabi (1956) recommended a design with feed and overflow widely separated horizontally. It was suggested that horizontal motion towards the overflow point would take place after the juice had become clear, in an approach to the ideal pattern shown in Figure 2. However, tests conducted at SRI using perspex tanks determined that the flow pattern approximated to that in Figure 3 and that sediment could be carried over with the overflow.

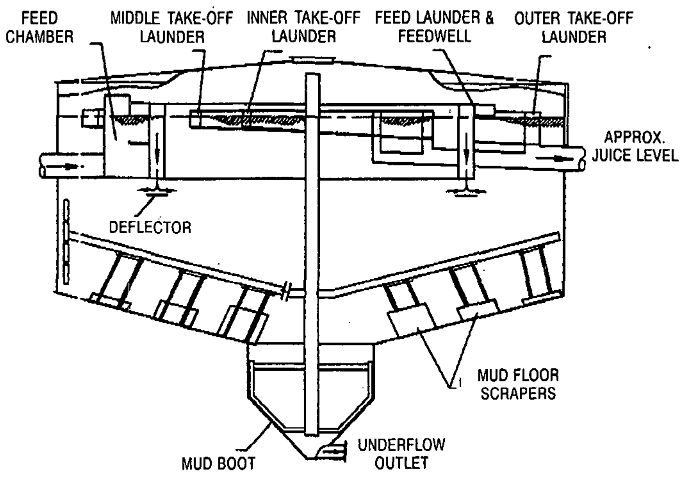

FIGURE 1: Sectional view of a standard SRI clarifier.

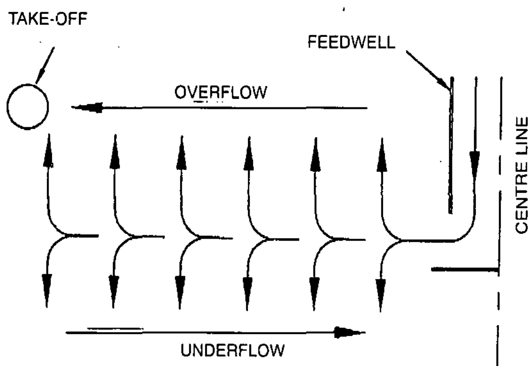

FIGURE 2: Ideal flow pattern according to Sabi (1956).

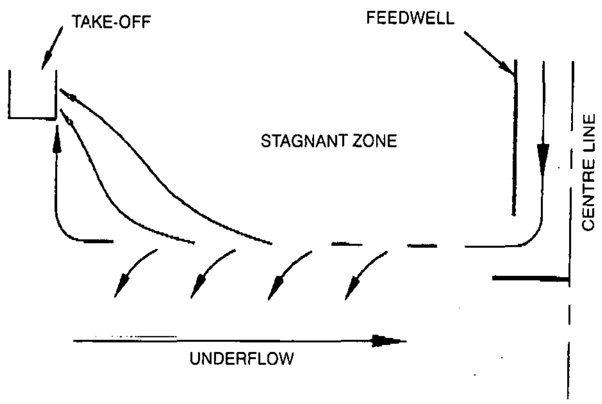

FIGURE 3: Approximate flow pattern from perspex tank tests at SRI.

The advantages of feeding through the 'multiplicity of openings' are that the horizontal distance to be travelled by the primary feed layer is reduced as is the initial horizontal velocity. Davis (1956) showed that the horizontal velocity of feed is inversely proportional to the distance from the centre of a circular tray. Moreover, if take-off points were located on both sides of the feed entry, the horizontal velocities would be reduced still further as shown in Figure 4.

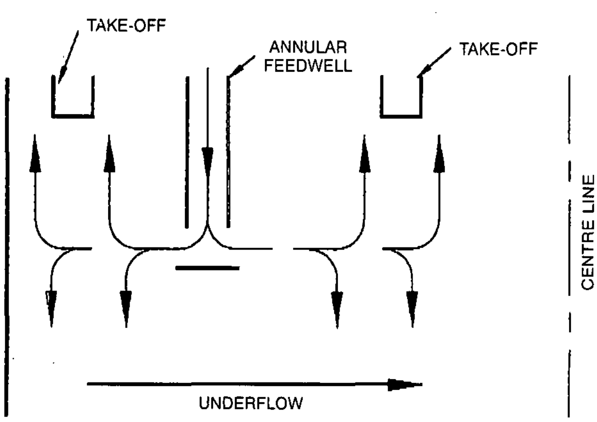

FIGURE 4: Flow concept of reduced cross-flow used to design the SRI clarifier.

The SRI clarifier design therefore minimised cross-flow by means of multipoint feed and take-off. An annular feedwell was employed with concentric annular take-off launders inside and outside the feed system. The design embodied the most positive multipoint feed arrangement that could operate on a continuous basis without causing floc damage from localised high velocity/high turbulence regions.

FIDAP model formulation

The clarifier was modelled as a two-phase flow in an axisymmetric geometry. A standard 12 m diameter SRI clarifier processing 600 m^3/h of juice was used to develop base case models of flow. It was possible to solve for the carrier phase first and then solve for the particle phase. The equations of the juice phase were the standard equations of fluid dynamics: momentum, mass conservation, energy, turbulent kinetic energy, and turbulent dissipation. The flow was assumed to be isothermal.

The forces acting on the mud particles were considered to be the drag force exerted by the juice, buoyancy due to the density difference and gravity. The density of the mud particle was estimated from a knowledge of terminal settling velocities. The terminal setting velocity was assumed to be equivalent to the initial settling rate measured in batch settling tests. This method could underestimate the true terminal velocity as hindered settling quickly masks the true settling rate. It was also assumed that, for the base case, the mud particles were 5 mm diameter spheres. Table 1 outlines the boundary conditions and the fluid and solid phase properties used in these simulations.

Table 1

Parameters for the clarifier simulation

Parameter	Unit	Value
Diameter	m	12,0
Feed rate	m^3/h	600
Feed velocity at top of feedwell	m/s	0,015
Juice viscosity	Pa.s	0,0005
Juice density	kg/m^3	1000
Particle density	kg/m^3	1000,2
Particle diameter	m	0,005
Particle settling velocity	m/s	0,005
Underflow rate	m^3/h	60

Results and discussion

Flow patterns in a standard clarifier

The streamline contour plot of Figure 5 illustrates the results obtained from a simulation of the flows in a standard 12 m diameter SRI clarifier using the conditions given in Table 1. There are strong horizontal flows leaving the gap between the feedwell and the deflector. These flows then decrease in velocity as they move towards the three take-off launders. The peak upflow velocities under the middle and outer take-offs are marginally lower than the assumed settling velocities. The predicted flows to each take-off launder are generally consistent with the cross-sectional areas served by each launder. The flow rates (as a percentage of the total clarifier juice flow rate) ranged from 13% at the inner launder to 64% at the outer launder. The flow patterns observed in factory installations using tracers and time measurements confirm the flow patterns predicted by the simulations.

The significant recirculation region below the deflector is of concern. The model predicts radial flow velocities away from the centre of about 0,005 m/s at the mud/juice interface which would tend to direct the mud phase towards the outer wall. The outer section of the clarifier floor is also expected to collect all of the mud from the flow serviced by the outer launder. A particle path plot for mud particles is given in Figure 6 and illustrates the effects of the recirculating flows in the region between the feed deflector and the floor of the clarifier.

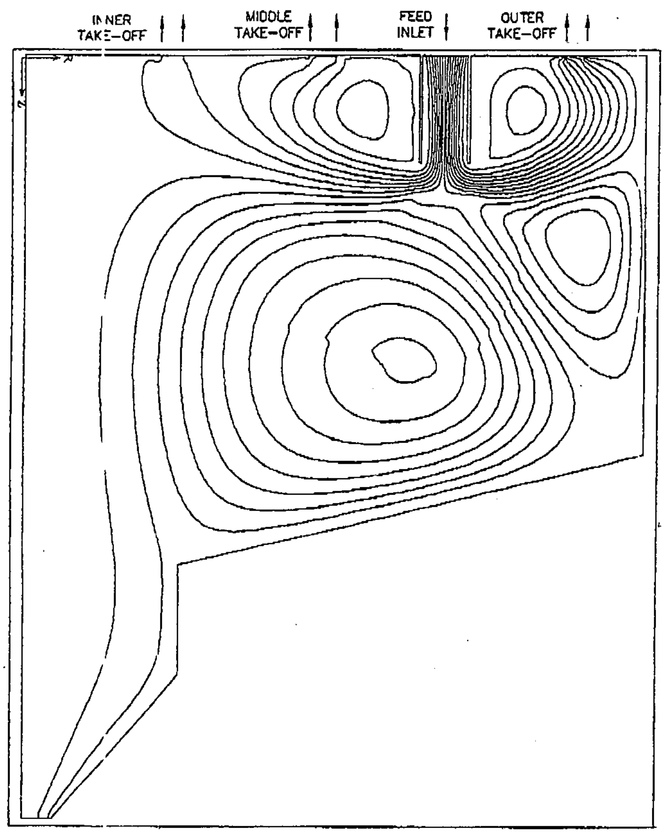

FIGURE 5: Streamline contour plot for a standard SRI clarifier.

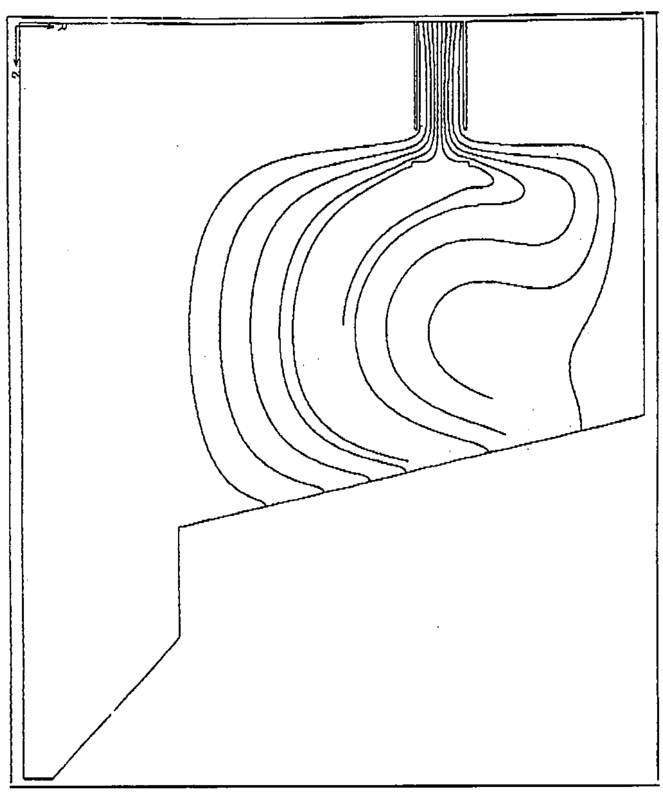

FIGURE 6: Particle path plot for 5 mm diameter mud particles with a density of 1000,2 kg/m³.

However, as shown in Figure 7, if mud particles of similar density but half the diameter (ie 2,5 mm) exist in the incoming feed, then some of these will be entrained by the clarified juice into the take-off launders. Conversely, mud particles of 10 mm diameter settle quickly to the bottom with only minimum deviation caused by any recirculating flows.

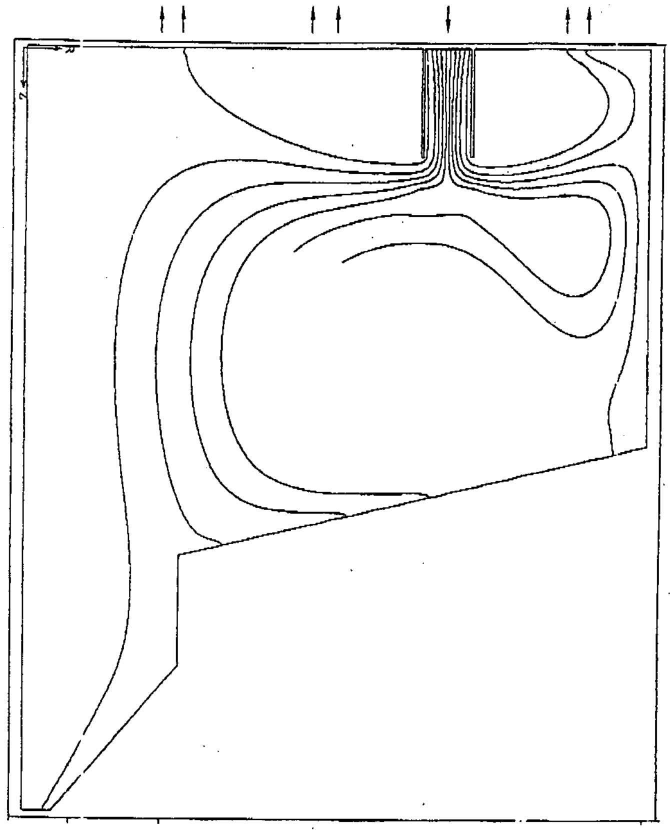

FIGURE 7: Particle path plot for 2,5 mm diameter mud particles with a density of 1000,2 kg/m³.

The particle path predictions emphasise the importance of selecting a flocculant that will produce large flocculated mud particles and a feed system design that minimises breakage of the mud flocs. If, by observing the size of the mud flocs in the feed launder and in the body of the clarifier, some breakage is occurring in the feed system, then modifications to the feed system would be warranted.

The availability of the CFD models enables investigations into variations of the standard SRI clarifier design or operating parameters. 'What if' scenarios such as varying the number of take-off launders, relocating the feedwell, changing the mud particle properties or varying the feed juice rate can all be easily examined without disrupting the factory operations.

SRI clarifier for Eston Mill

Sugar Research International was successful in obtaining a contract through its South African agent, Sugarequip Pty Ltd, to supply the design for a new 10,7 m SRI clarifier for the Eston mill project. On the request of Illovo Sugar Ltd, the standard SRI clarifier design was modified to satisfy the technical specification supplied by Illovo Sugar Ltd. In particular, the specification nominated an average suspended solids loading in the clarifier feed of only 0,25% and a mud residence time in the clarifier of approximately 60 minutes. The modifications included:

- A reduction in the wall height of 0,6 m. This effectively reduced the space between the deflector and the mud floor by 0,6 m in recognition of the much lower mud solids loading and reduced residence time.

- A reduction in the slope of the mud floor to 8°.
- Replacement of the mud cone with a conical shape.

The length of the feedwell was extended a further 0,5 m into the mud settling zone resulting in an overall reduction in the mud settling zone of 1,1 m. Under Australian conditions where mud loadings can vary significantly in a short time, this loss of buffer capacity could not be tolerated.

The final design of the clarifier accepted for Eston was examined using the CFD modelling techniques developed previously. The mud/juice interface was assumed to be static and level with the intersection between the mud floor and the side wall of the vessel. The interface was considered to be a porous surface where the fraction of the clarifier feed rate that passed through the porous interface as underflow could be nominated. This assumption allowed the mud cone and floor to be ignored in this analysis.

The CFD analysis using the Eston geometry predicted streamline flows as shown in the contour plot of Figure 8. The result was similar to those obtained for the standard SRI clarifier except that there is a very much reduced flow below the deflector. Juice flow velocities are much lower than might usually be encountered in an Australian installation because the Eston clarifier is oversized for the required duty.

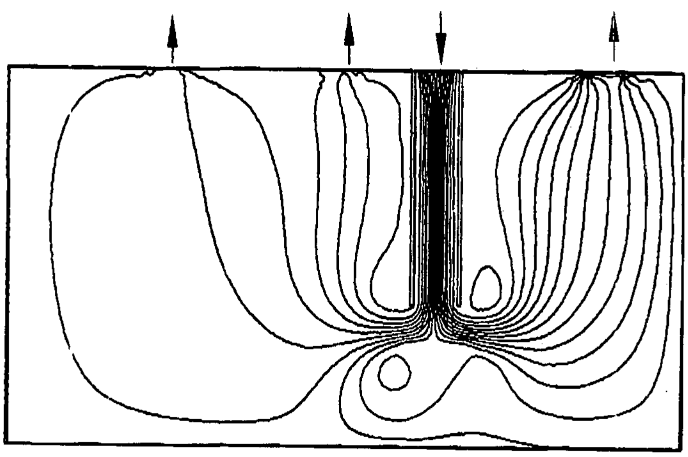

FIGURE 8: Streamline contour plot for the clarifier designed for Eston Mill.

From the model predictions of the Eston clarifier design, it is expected that there should be no adverse effects on the clarification performance from the design modifications that have been implemented.

Conclusions

The concept of computational fluid dynamics modelling has been discussed and a number of potential applications within the sugar industry have been introduced. One of the first applications that has been investigated at SRI was an analysis of the flows occurring in a SRI clarifier using the CFD code FIDAP.

The results of the simulations performed indicate that the predicted flows are in general agreement with the flows that have been observed in factory installations. The model predictions have emphasised the importance of achieving high settling rates with large flocculated mud particles.

The availability of the CFD package and base clarifier models have allowed an investigation of a modified clarifier design before actual construction commenced. In this particular case the design supplied for the Eston mill project is expected to provide optimum clarification performance for the conditions specified.

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