

A JUICE CLARIFIER WITH TURBULENCE REDUCTION DEVICES: RESULTS OF FIRST INDUSTRIAL TRIALS

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Abstract

Optimisation of juice clarifiers has been the subject of multiple studies that have led to the development of a number of efficient designs. Computer-aided simulations of the clarifiers using various CFD packages demonstrated that the presence of turbulent eddies were responsible for efficiency reduction. The clarification process is especially important for Louisiana sugar mills due to the climatic conditions and the type of soil that lead to elevated mud levels. With increased demand for higher quality sugar and continuous efforts to reduce inversion losses, the improvement in clarifier operation is timely. A new design of trayless juice clarifier has been tested in a Louisiana sugar mill. A simple juice distribution system comprises a number of feed pipes uniformly distributed over the cross-sectional area. The exit points of the pipes are supplied with turbulence reduction devices that dissipate the momentum of the feed juice, thus eliminating turbulence eddies. A 6 m diameter modified clarifier was operated in parallel with a 6 m diameter Graver clarifier and 10 m diameter Rapidorr. The modified clarifier initially performed at a 25% higher feed flowrate than a Graver clarifier and delivered juice with 20-25% lower turbidity. It also compared favorably with a Rapidorr clarifier that had twice the residence time. The new design is promising as it delivers a simple retrofitting option. Operating results and areas for optimisation are discussed.

Keywords: clarifier, juice, turbulence reduction, sucrose loss, CFD modelling

Introduction

Importance of the cane sugar clarification process has been acknowledged by cane sugar technologists for many years. Clarification arguably influences all stages of production of raw and (later) refined sugar. Although it is difficult to completely isolate the impact of each individual quality parameter of the clarified juice on mill operation, discussion in Table 1 illustrates the significance of the clarification stage and the expected economic impacts on mill and refinery operations.

A standard clarifier design involves a cylindrical tank with a sloped base with or without a raking mechanism for thickened sludge removal (Swarovsky, 1990). Although a number of clarifier designs have been tested over the years, few have found extensive application in the sugar industry. In most conventional multi-tray clarifiers, such as Rapidorr, liquid has to travel horizontally outwards and vertically upward following the pathway from central feed well to overflow launders (Rein, 2007). In the Graver clarifiers, liquid travels from the periphery of the tank toward the central juice outlets, while precipitated solids slide off the

trays into a mud boot. The horizontal travel reduces efficiency and throughput of the clarifier. It also creates large-scale circular motion inside the clarifier, decreasing both capacity and separation efficiency.

Table 1. Influence of clarified juice quality parameters on cane mill operation.

Juice quality parameter	Process impact	Economic impact
High level of turbidity and suspended solids in the clarified juice.	<ul style="list-style-type: none"> • Heterogeneous nucleation in the crystallisers, contribution to non-uniformity of crystal population (van der Pol <i>et al.</i>, 1998). • Increased washing requirements. • Poor crystallisation kinetics resulting in direct energy loss. • Increased scaling and poor heat transfer. • Occlusions in sugar crystal. • Increased sugar washing to improve quality dissolves additional sugar that is eventually recycled back into the process. This results in additional colour build-up and additional sugar losses to inversion. Additional energy is required to recover 'washed' sugar. • Accumulation of fine bagacillo in the centrifuges. 	<p>Increased sugar losses.</p> <p>Increased energy use for evaporation.</p> <p>Low sugar quality - higher refining cost.</p> <p>Reduction in mill capacity.</p> <p>Energy losses.</p> <p>Higher operating and maintenance costs.</p>
High colour	<ul style="list-style-type: none"> • High raw sugar colour. • Additional crystallisation for colour control. • Potential increase in non-sugar recycle. 	<p>Low quality - potentially less marketability, higher refining costs.</p> <p>Energy losses.</p> <p>Throughput reduction of crystallisation equipment.</p>

Through utilisation of advanced modelling and visualisation techniques such as computational fluid dynamics (CFD), the inefficiencies of existent clarifiers have become even more obvious. Presence of large-scale turbulence has been confirmed by multiple CFD studies by South African (Peacock *et al.*, 2000; Chetty and Davis, 2001) and Australian (Steindl, 2001; Steindl *et al.*, 2005) researchers. Velocity vectors in the contour plot in Figure 1 clearly illustrate the reasons for relatively low efficiencies of clarifiers that deviate from the vertical flow pattern.

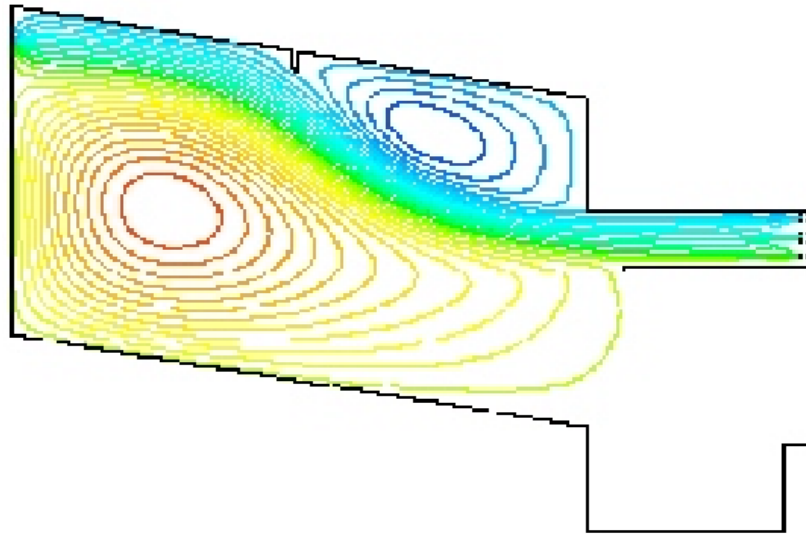


Figure 1. Hydrodynamic condition in a Rapidorr clarifier (Chetty and Davis, 2001).

Several efficient clarifier designs exist that so far have not found applications within the sugar industry, such as the ‘lamella’ clarifier (<http://www.imswe.com/watertreatment/Pretreatment/Clarifiers/lamella/lamella.html>) [accessed April 10, 2010]. The main feature of such devices is a stack of parallel inclined plates inserted in a rectangular vessel, which shortens sedimentation pathways. Proper juice distribution between the plates remains one of the challenges for such devices (Echeverri, 2005). A variation of the lamella idea is an EIMCO’s ‘delta-stack’ clarifier (<http://www.flsmidthminerals.com/Products/Sedimentation/Delta-Stak+Clarifiers/Delta-Stak+Clarifiers.htm>) [accessed April 10, 2010] that differs in the configuration of liquid outlets. The design features a stack of small parallel plates with a few centimetres of space between each other that provide additional surface area for settling. Removal of solids and cleaning issues are critical in these types of design. The cost is significant, especially where the material of construction is other than plastic (which is not applicable to high temperature sugar solutions). Sludge thickening may not be used to the advantage of the separation.

For years, researchers have focused their efforts on reduction of clarifier residence time, optimisation of clarification regimes, and changing internal construction to improve hydrodynamic conditions. Over the past three decades, Australian researchers at the Sugar Research Institute have developed several generations of continuous short residence time clarifiers that proved efficient. In the recent design that was optimised to reduce formation of large-scale eddies, Steindl *et al.* (2005) claims that 30 minute residence time can be accomplished compared with traditional clarifiers (almost 1-2 hours). The design improvements come at additional cost and require significant internal structure for juice inlets and outlets. Retrofitting options with new designs are quite limited. It is the purpose of the current paper to outline a different approach to clarifier design that allows economically attractive retrofitting solutions. Results of preliminary design, prototype testing and industrial implementation are discussed below.

Design concepts

The following basic considerations laid the groundwork for the design of a new trayless clarifier.

1. A fluid distribution network needs to be created inside the vessel that introduces juice through a series of hydraulically uniform pathways. The endpoints of such pathways should be distributed uniformly across the cross-section of the clarifier.
2. Feed juice should be introduced into a bottom third of the clarifier to allow space for mud settling and thickening. Juice distributors have to be located above the mud level.
3. Velocity in the feed channels should remain relatively high to eliminate potential plugging/scaling.
4. Endpoints of the distribution piping should be supplied with turbulence reduction devices to dissipate the momentum of the liquid jet exiting the pipe. The scale of turbulent eddies created at the exit points can thus be reduced.
5. Liquid overflow should be collected through a series of uniformly distributed outlets at the top portion of the clarifier. This feature maintains uniform vertical juice velocity profiles to make full use of the cross-sectional area of the clarifier.
6. Internal structures inside the clarifier should be minimised to reduce the overall cost of construction and retrofitting.
7. New design should provide relatively low residence time of about 30 minutes that corresponds to state-of-the-art short residence time clarifiers.

The proposed design features were intended to alleviate the horizontal components of liquid flow responsible for creation of large turbulence eddies. A uniform flow pattern has to be established, where the solid-liquid separation should be determined by a difference between particle settling and the upward velocities.

Initial CFD modelling

Construction of a device to achieve turbulence reduction at the end point of the feed pipe appeared to be the most challenging task of the new design. A combination of high velocity in the pipe and fluid momentum cancellation at the exit point has not been successful in the past designs. The need for the turbulence reduction is illustrated by a test, where a food grade dye was injected into a circulation loop of a water tank. Water was pumped through an 8 cm diameter hose at a rate of 23 m³/h. Visualisation of the resulting flow pattern is presented in Figure 2. As expected, significant turbulence was observed with very little dispersion of the dye inside the vessel.

A deflection plate was initially considered as a simple device that would cancel momentum of fluid and disperse it inside a clarifier. A device consisting of two parallel plates with liquid introduction into the space between the plates was constructed. The two plates were connected by four bars that formed a 'box' with four vanes to distribute liquid sideways.

Prototype testing using dye dispersion was conducted again. Although the flow pattern improved considerably and the jetting was reduced, certain turbulence was still observed.



Figure 2. Tracer injection into a water tank (pipe diameter 8 cm, flowrate 23 m³/h).

For visualisation of flow patterns in the prototype, a CFD modelling of such device was performed by specialists from Amalgamated Research Inc. (Twin Falls, ID, USA). A diagram showing velocity profiles is shown in Figure 3. The blue lines show the outlines of the distribution box. Contrary to the expectations, liquid was not reversed by a deflection plate, and the area between the plates was not utilised completely by the flow. Instead, the flow was ‘hugging’ the bottom plate, and the velocity of liquid leaving the plate was even higher than that in the core of the flow. However, a certain amount of turbulence reduction was achieved.

After several design iterations, the internal construction was modified to achieve almost complete turbulence reduction. In the final version, the jet flow was reversed several times after leaving the volume encased between the parallel plates. No additional CFD modelling was carried out to optimise the elements of internal construction. For demonstration purposes, a food grade dye was injected into water that was recirculated at a rate of 23 m³/h. Two consecutive pictures of dye dispersion show almost a complete lack of turbulence during introduction into a half a cubic metre of water (Figure 4). The surface of the water stayed calm. The bubbles on the surface were caused by cavitation of the circulation pump rather than by the turbulent eddies.

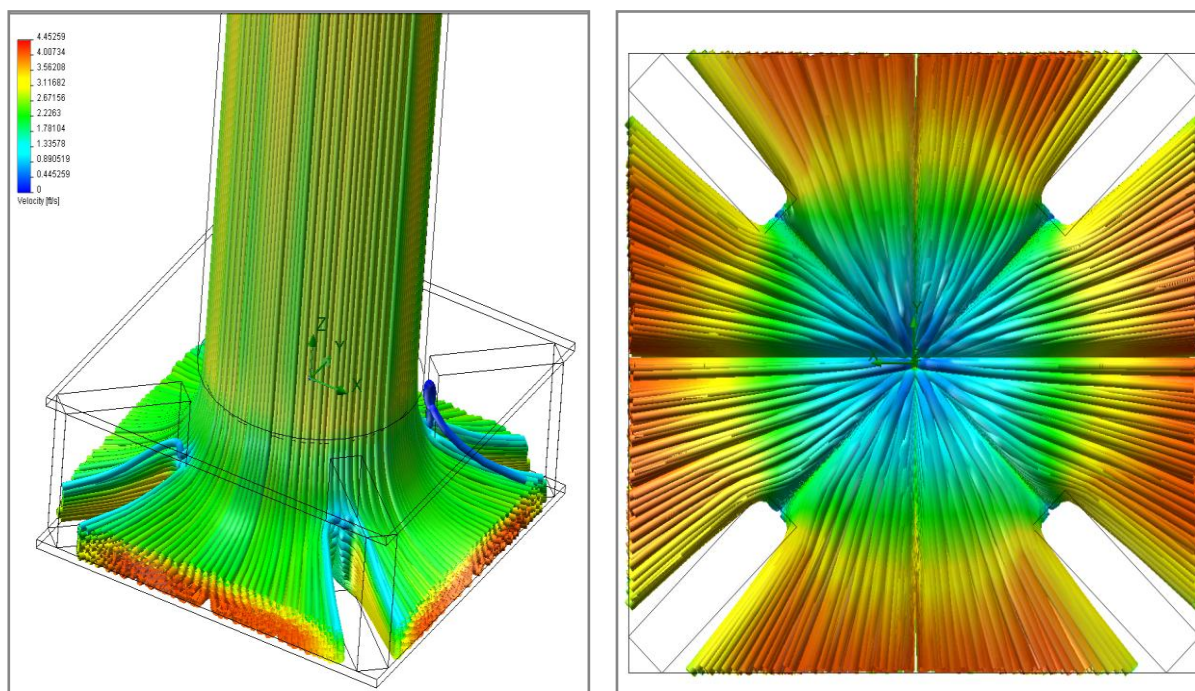


Figure 3. A CFD model of flow into a device supplied with a deflection plate.

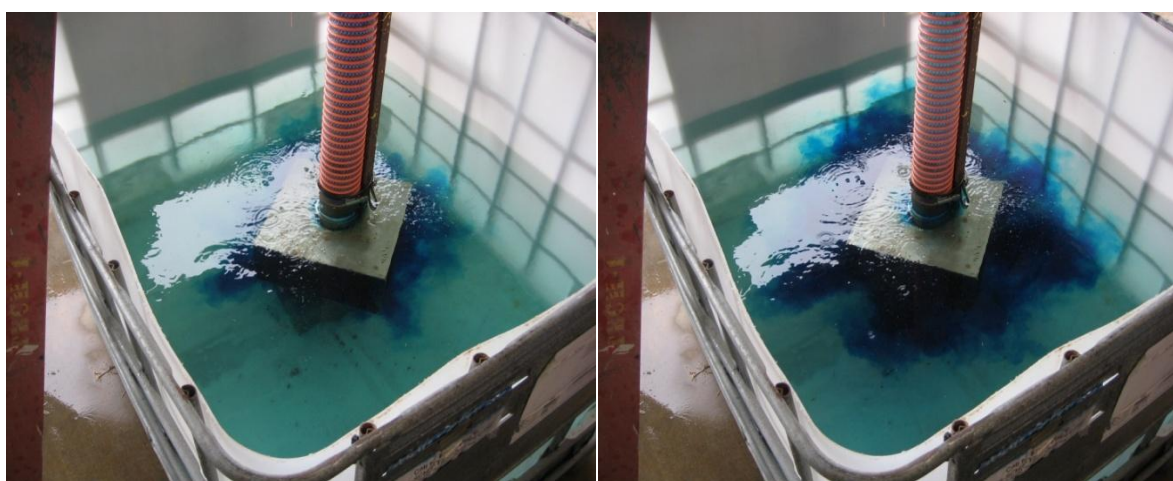


Figure 4. Tracer injection into a turbulence reduction device (consecutive pictures).

The results appeared satisfactory, and further device optimisation was stopped as one of the sugar mills decided to install the developed turbulence reduction devices for the coming season. The project effort was then redirected towards industrial implementation. A provisional patent application has been filed for a turbulence reduction device (TRD) (Kochergin and Gaudet, 2009).

Industrial implementation

An old Graver clarifier in a Louisiana sugar mill was modified using new design features. Clarifier diameter was 6 m; and the height was 7.5 m, including the conical bottom portion. The old trays were removed, and the overflow collection launders were installed and carefully

levelled to provide uniform juice removal from the clarifier surface. No modifications have been made to the mud removal system or clarifier rakes.

A juice pre-distribution unit was designed by factory specialists to feed juice from the flash tank uniformly into nine vertical pipes supplied with turbulence reduction devices (TRDs) at juice exit. The number of outlets was selected based on expected throughput. A schematic representation of the TRD layout inside the clarifier is shown in Figure 5. To minimise the scale-up risk, the pipe diameters and flowrates closely matched the parameters of the prototypes tested during the pilot trials. The TRDs were distributed uniformly across the clarifier and positioned about 1.5 m above the bottom of the tank. Although pipe lengths leading to TRDs were different, the pre-distribution unit supplied exactly the same flow to each pipe.

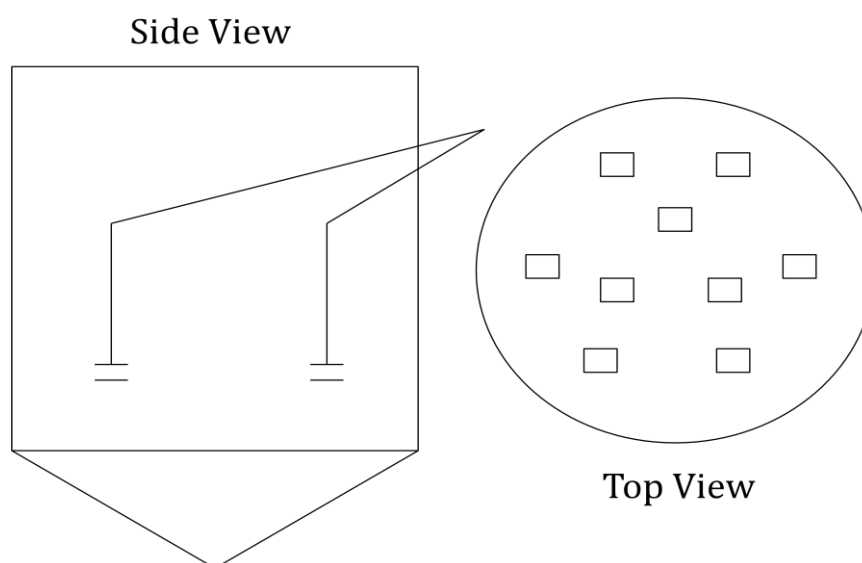


Figure 5. Layout of TRD inside the clarifier.

The dimensions of the clarifier housing have not been optimised due to logistical considerations. Thus, the ratio of height to diameter was rather high compared to the desired ratio.

Experimental procedures

Most of the season, with the exception of few mechanical shutdowns, the sugar mill operated a 6 m diameter Graver, a 10 m diameter Dorr clarifier with two mud boots and a 6 m diameter clarifier retrofitted according to the new concepts. Main focus of the study was to evaluate the new design and identify areas for future optimisation. Comparison of the clarifiers operated in parallel with the experimental design was considered useful. It was understood that the operation of each clarifier was dictated by the process requirements rather than by the needs of the experimental programme. No attempts were made to set up and execute an experimental plan with variable flowrates and mud removal rates.

Turbidity of the clarified juice was monitored periodically throughout the grinding season using a Hach 2100 P Turbidimeter (www.hach.com). Samples were also centrifuged in the clinical DynacTM centrifuge to qualitatively determine the presence of fibrous material. Samples were put into a 15 mL tube and spun for 3 min. Mud samples were centrifuged using

the same procedure. Juice flowrates were determined from the readout of factory flowmeters. Flocculant flowrates were calibrated several times manually using a graduated cylinder.

Results and Discussion

The 2009/10 grinding season in Louisiana was characterised by extremely high mud levels due to record rainfalls. In the Westfield plant mud levels of 12-15% on cane were registered throughout most of the season. Variation of flowrates through the three mill clarifiers during the season are shown in Figure 6. Corresponding clarified juice turbidities are presented in Figure 7. The data was fitted using polynomial regression to show the trends.

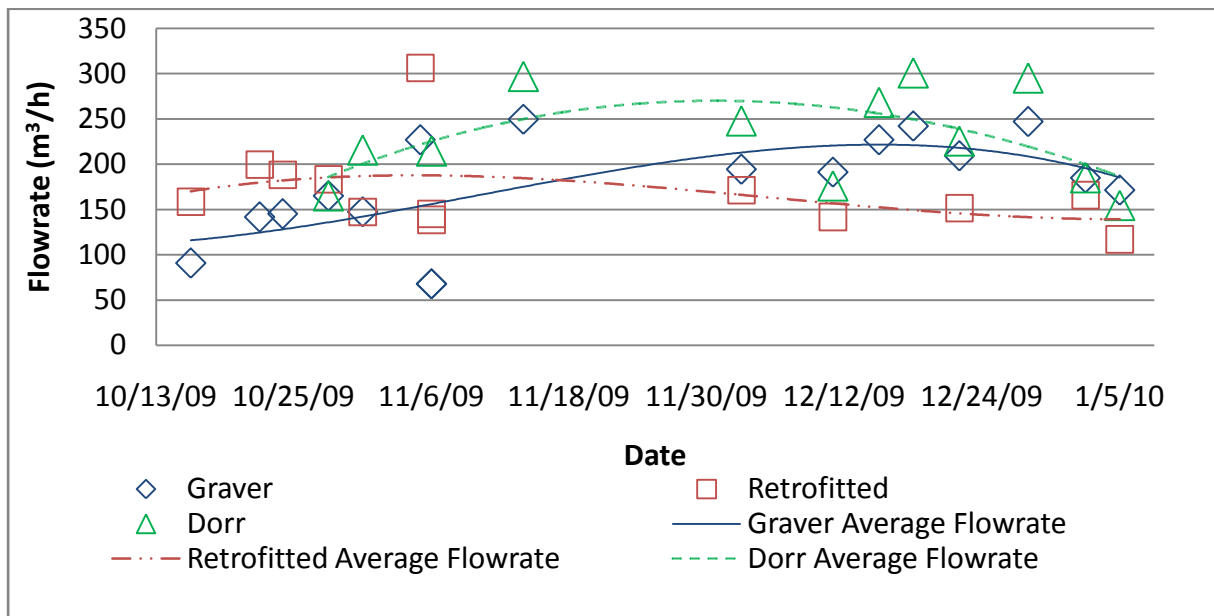


Figure 6. Measurement of industrial clarifier flowrates.

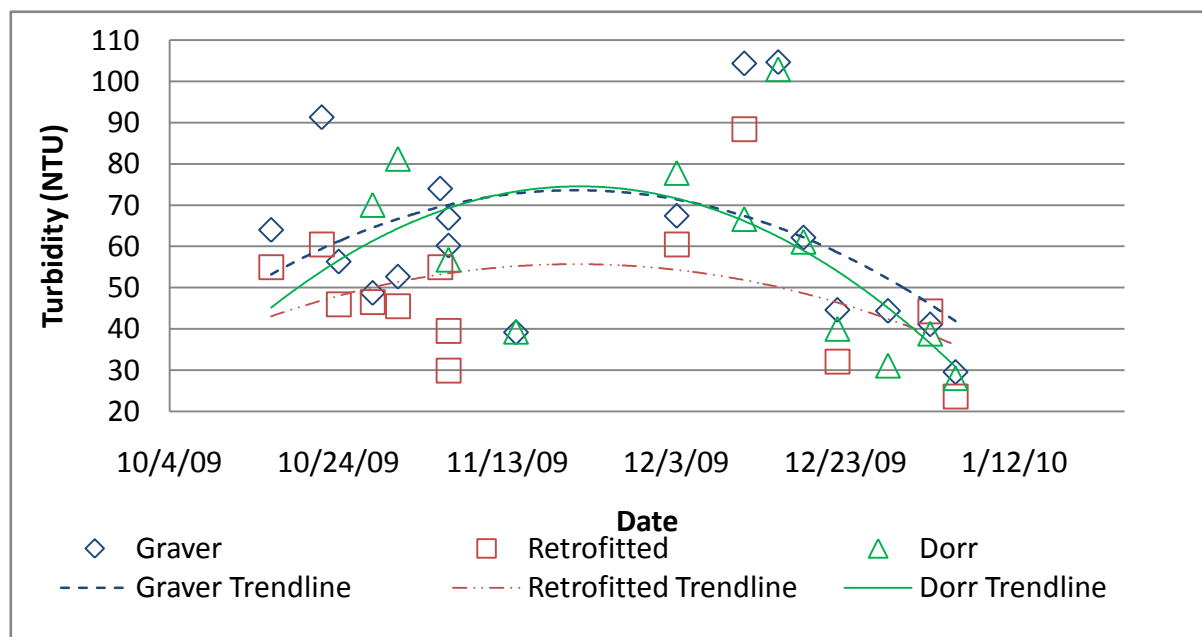


Figure 7. Clarified juice turbidity data.

Because of mechanical problems, the Dorr clarifier was shut down for a few days in the beginning of November, which required additional load on the two remaining clarifiers. At that time the retrofitted clarifier performed well above the expected capacity with low juice turbidity. Later, the retrofitted clarifier was shut down for about 10 days due to mechanical problems not related to design. When it was brought back on line, it was operated at a slightly lower rate compared to the beginning of the season. The retrofitted clarifier provided better juice turbidity than the Dorr clarifier despite twice the residence time in the latter. Clarified juice turbidity was also better in the retrofitted design than in the Graver clarifier at comparable conditions.

Fibre content in the clarified juice was evaluated qualitatively by spinning a 15 mL juice sample in the centrifuge. If fibrous material was present, it formed a small layer of scum on the bottom of the test tube. Clarified juice from the retrofitted clarifier appeared to have slightly more fibre despite its superior turbidity. Apparently, fibre content and turbidity are not well correlated.

The surface of the clarifier was examined through several top hatches. In one portion of the clarifier the liquid was turbulent, which was related to air entrainment in the pre-distribution system. Corresponding photos are presented in Figure 8. Air entrainment was also causing local mixing and potential fibre entrainment, especially when operators occasionally kept the mud level well above the distributors (sometimes as high as 1.5 m). In this case mud flocs were broken, and the fibres were lifted to the top. Vertical turbidity profiles presented in Figure 9 support this conclusion. Clarified juice samples were collected from the entire cross-sectional area of the clarifier and from two ports positioned at 168 and 285 cm below the top level. The sample ports were collecting juice only from the area adjacent to the clarifier wall; hence, they were least affected by the turbulence induced by air entrainment in a portion of the clarifier. In most cases, juice collected from the entire clarifier surface had higher turbidity than the samples collected from the sample ports. Air entrainment apparently has less affect on the areas next to the clarifier walls, where sample ports were located.



Figure 8. Surface conditions in the different hatches of the retrofitted clarifier.

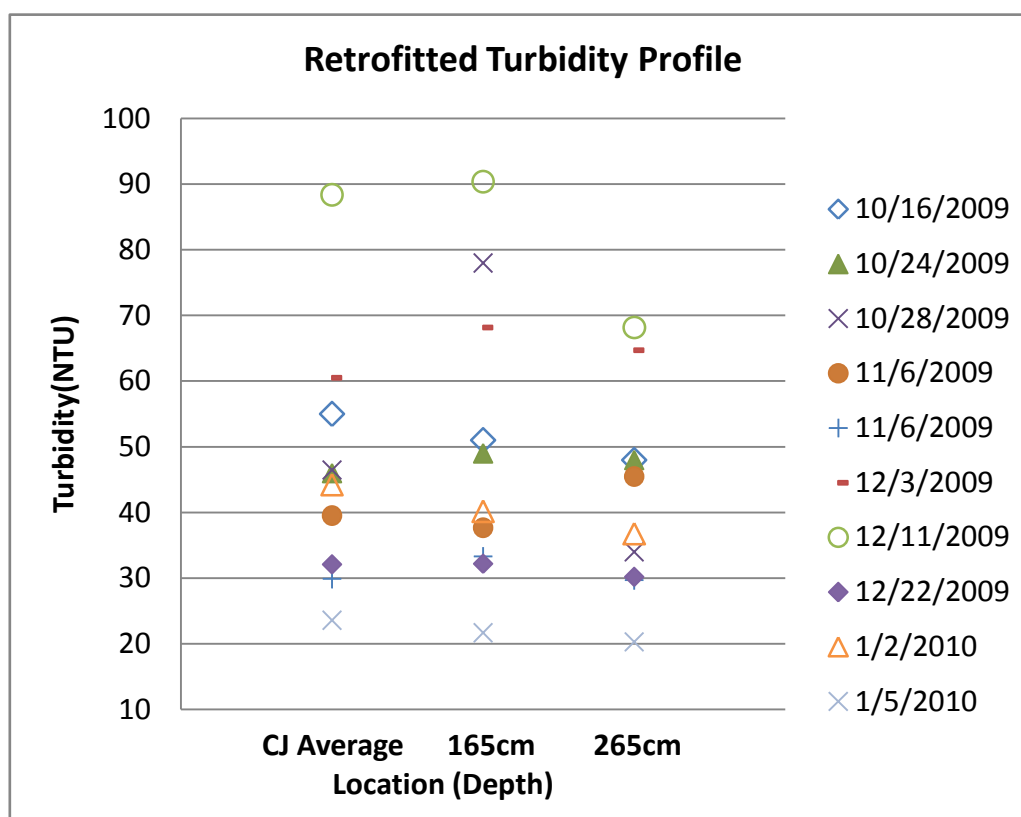


Figure 9. Vertical turbidity profiles.

The data in Figure 9 also confirms that once the solids and liquids are separated, the height of liquid collection above the distributors is not important in the absence of turbulent eddies. In the absence of turbulence, further reduction of height to diameter is desired. It is apparent that the clarifier height can be reduced by at least 1.5 m without any damage to clarifier performance. A 20-25% reduction in residence time can thus be achieved. In a completely new design, the height to diameter ratio issue has to be revisited.

Because of operational issues related to air entrainment and mud level control that interfered with clarifier performance, no attempts were made to optimise the location of the flocculant addition point. On average, the retrofitted clarifier consumed more flocculant. It was difficult, however, to estimate the extent of the impact of this parameter on clarifier performance. New clarifier performance can be improved even further by elimination of the operational problems discussed above.

Conclusions

- New clarifier design proved technically feasible. The retrofitted clarifier demonstrated good performance most of the season despite some operating constraints, sometimes at higher than expected capacity.
- Retrofitted clarifier initially performed at a 25% higher feed flowrate compared to a Graver clarifier and delivered juice with 20-25% lower turbidity. It also compared favorably with a Dorr clarifier that had twice the residence time.

- Fibre content in the new clarifier was generally higher than other clarifiers due to air entrainment in the pre-distribution system. Modifications have been developed and will be installed during the following processing season.
- Operators did not exercise reliable mud level control in the new design (mud level was often maintained above juice distributors).
- Clarifier retrofitting of the new design in the sugar mill was accomplished within several weeks, which presents an opportunity for rapid optimisation of existing equipment and with minimal investment.

Future work

Juice pre-distribution system needs to be optimised to eliminate the potential of air entrainment.

Mud level control has to be improved to assure that the level is always maintained below juice distributors.

CFD modelling of the turbulence reduction devices (TRD) will be continued to optimise the proportions as a function of juice flowrate and the geometric dimensions of TRDs. Physical testing of the prototypes and evaluation of CFD modelling adequacy would be of interest.

CFD modelling of the entire clarifier will be performed to optimise the number and position of TRDs in the clarifier.

Acknowledgements

Andy Cluff from Amalgamated Research Inc (ARi) for support with CFD modelling; personnel of Westfield, St. Mary and Sterling Sugar Mills; and colleagues at Audubon Sugar Institute.

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