Performance of lamella clarifiers for juice and syrup clarification

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Abstract A new design for syrup and juice clarifiers is presented. The design takes advantage of the considerably improved performance of clarifiers incorporating lamella plates, and the reasons for the improvement are outlined. Computational fluid dynamics (CFD) work done to simulate the performance is summarised. This design enables the residence time to be dramatically reduced and the simplified design leads to cheaper and better clarifiers. Practical experience with factory scale units is described, confirming the good flow characteristics. The results of preliminary test work on a factory syrup clarifier are presented, which is also shown to operate efficiently as a phosphatation clarifier. In addition the performance of a full-scale juice clarifier has been evaluated and compared with the performance of a Rapidorr clarifier. This work confirms the considerable advantages which this type of design provides, in realising substantial reductions in residence time, capital costs and operating costs.

Key words Clarification, juice syrup, liquor, lamella clarifier, efficiency

INTRODUCTION

Juice clarification is an important step in the production of sugar, and syrup clarification is widely used particularly when good quality sugar is to be produced. The latter is very similar to the process of phosphatation employed as a clarification process in refining. The process industries in general frequently use clarification processes, either as settlers or dissolved air flotation (DAF) units. In both cases substantial advances have been realized when clarifiers have been fitted with lamella plates, which can be usefully employed to improve the efficiency of separation.

Recirculation and short-circuiting of juice in clarifiers was identified many years ago (Love 1980; Peacock et al. 2000). Tracer tests showed some juice exiting the clarifier within 10 to 20 minutes in clarifiers with a nominal residence time of 90 minutes. Residence time plots show a prolonged ‘tail’, with some juice leaving the clarifier only after a few hours. This provided evidence of both short circuiting and recirculation within the clarifier, which was confirmed by computational fluid dynamics (CFD) modelling work (Chetty and Davis 2001; Steindl et al. 1998, 2005). Some modifications made to the different types of clarifier have helped but not solved the problem. Thus the nominal residence time in Rapidorr clarifiers can be reduced from a few hours to 45 minutes. The residence time in so called ‘short residence time’ clarifiers developed in Australia was around 45 minutes, but the ‘new generation’ design has reduced this to about 30 minutes or 20 minutes at best. The theoretical settling time required, assuming a settling distance of 1.5 m and 150 mm/min settling rate, is 10 minutes. Most of the existing clarifiers do not get close to this.

A lamella clarifier eliminates the prospect of recirculation, and with it short circuiting. In addition it reduces the settling distance from 1 or 1.5 m to just 50 mm, the distance between adjacent lamella plates. It is inherently capable of substantially improved performance.

Because of the size required for clarifying the juice, juice clarifier diameters are large. Thus all clarifiers require rotating scrapers to move the mud to a central offtake point. Mud residence time has been measured in an SRI clarifier in Australia to be around 100 minutes (Steindl 2007). In addition this work has shown that the so-called mud thickener in the mud boot does little in the way of increasing mud density; the final mud density is not dependent on the depth of the mud, and the maximum density is achieved within 30 minutes. The lamella clarifier with its rapid separation and small diameter does not require a stirrer or rake.
The use of lamellas in water clarifiers has been shown to improve capacity by a factor of 4 to 10. It is now a well-established technology. This approach leads to laminar flow between lamella plates, which together with short settling distances, means that solid particles are rapidly and efficiently settled. There is no chance of floc particles being entrained by circulation patterns evident in conventional clarifiers.

The parameter typically used to describe the performance of clarifiers is the surface load rate, which relates the volumetric flow to the total plan clarification area, giving an average superficial vertical velocity. In practice liquid surface loadings in the range 2.5 to 15 m$^3$/(m$^2$.h), or m/h, are used in treating water using DAF. A breakthrough in flotation water treatment came with the introduction of lamellas, where units on water treatment provided with lamella plates can achieve higher load rates (30-40 m/h).

It was realized that the same degree of separation efficiency improvement might be possible if the same technology was applied in sugar processing. The first step in the development was the simulation of the settling processes using CFD that was carried out at the Audubon Sugar Institute in Louisiana.

**CFD STUDIES**

The work on syrup clarification was reported by Echeverri and Rein (2006a). Use was made of results from an experimental study of the hydrodynamic behaviour of the flocs. Based on the predicted flow field, the dynamic response of the clarifier was simulated to obtain a residence time distribution, which was validated by comparing predicted results with tracer tests performed in Tongaat Hulett sugar mills. It is concluded that single-phase CFD solutions cannot describe correctly the flow in syrup clarifiers, where the buoyancy of the flocs appears to affect the flow field. The application of a two-phase model gave better agreement with tracer results, and indicated possible flow patterns within syrup clarifiers. The numerical analyses suggested significant effects of the size of the flocs, the positioning of the outlets and the existence of stagnant zones on the flow patterns. The introduction of inclined channels, or ‘lamellas’, within the flotation area to optimize the flow patterns was investigated, concluding that they are effective in preventing recirculation and turbulence, and help to increase the throughput of syrup clarifiers substantially.

Simulation of the flow patterns in a lamella clarifier handling 60 t/h syrup are shown in Figure 1. The loading rate is 20 m/h, considerably larger than the industrial Empangeni clarifier simulated with a loading rate of 3.8 m/h. Further simulations showed that the flow could be increased to 180 t/h without entraining floc in the underflow.

*Fig. 1. Syrup streamlines (top) and contours of scum volume concentration (bottom) predicted for a lamella syrup clarifier orienting the plates (left) with and (right) against the inlet flow stream Colour legend gives volume fraction of scum.*
Simulation of a juice clarifier was undertaken and the results presented at an ISSCT Processing Workshop in 2006 (Echeverri and Rein 2006b). The simulation showed that a surface loading of 34 m/h should be quite practical, based on an initial settling rate of 150 mm/min. The Reynolds number in the flow channels was 940, well within the laminar region, while Reynolds number values for other types of clarifiers indicate turbulent flow in all cases.

SYRUP CLARIFICATION

Syrup clarifier description

A syrup clarifier with 37 plates 1.22 m wide was manufactured and installed at the SER San Antonio factory in Nicaragua, with a volume of 5.5 m$^3$, designed to handle 45 m$^3$/h of syrup. The design follows the arrangement which was simulated, with the syrup entering from the side, the scum being removed from the top surface, and the clarified syrup being withdrawn from the bottom. It flows out over an overflow weir, the height of which can be changed to achieve the required scum layer thickness.

The lamella clarifier was installed in parallel with 3 existing conventional syrup clarifiers, each 5.64 m in diameter and with a volume of 43.7 m$^3$, each designed for the same flow rate of 45 m$^3$/h. Figure 2 shows a representation of the lamella clarifier that was installed. Initially the scum was scraped manually off the top of the clarifier when it was first commissioned, and subsequently a scraper assembly was installed to remove the scum layer continuously.

![Fig. 2. Perspective view of the lamella clarifier.](image)

Flow characteristics

A tracer test was undertaken to assess the flow characteristics. A saturated salt solution was added at the inlet to the clarifier and conductivity readings were taken on clarified syrup samples collected over the following 20 minutes. Salt is not an ideal tracer, since the baseline conductivity varies substantially as the ash and dissolved solids contents of the syrup vary. The flow rate was 45 m$^3$/h, accurately measured by a magnetic flow meter, and the results are shown in Figure 3 together with the estimated salt baseline. They give an excellent representation of a close approach to plug flow, particularly as the salt solution was added over a period of 2 to 3 minutes due to a pipe size restriction, representing more like a step than a pulse input. The tracer response was modelled using a tanks-in-series model (Levenspiel 1962), which showed a
very good fit with 15 tanks in series, and an average residence time of 5.9 minutes. The predicted mean residence time based on the clarifier volume was 6.7 minutes. This is good agreement in view of the uncertainties mentioned.

![Fig. 3. Tracer test measurements on San Antonio lamella syrup clarifier.](image)

This represents a loading rate of 19.5 m/h. The substantially reduced residence time should minimise colour formation and any sugar degradation reactions.

**Operational performance**

Measurements and analyses were undertaken comparing the performance of the lamella clarifier with that of the existing clarifiers, run in parallel. The important parameter in judging syrup clarification is turbidity (Rein 2007). Turbidity removal should be above 80%, and it is difficult to judge performance using other parameters because the differences are small.

The first period of operation lasted a week when scum was raked manually from the clarifier. During this period, other operational problems affected performance, in particular the stirrers in the aeration tanks and reaction tanks (where lime and phosphate were added) were not operational, as well as problems with control of flocculant (at a lower than optimum dosage rate). Nonetheless, this period showed a turbidity removal of 62.9%, which because of these issues was low, but was still 7.1% higher than that achieved by the existing clarifiers. Turbidity was measured according to the ICUMSA Method GS7-21.

A second test period was undertaken when a scum rake was fitted to the clarifier. Again this period was affected by control problems, but achieved turbidity removal of 79.5%, compared to 69.9% in the existing clarifiers.

Two further periods of testing (periods 3 and 4) were carried out. In these tests, samples of crude syrup, clarified syrup and syrup from the lamella clarifier were compared. The results for period 3 are shown in Table 1. During this time the flow to each clarifier was 35 m³/h.
The data show considerable scatter, as is expected with factory operation. Statistical measures were used to establish confidence levels in the observed differences between the syrup from the lamella and the total treated syrup stream. Note the latter also includes the syrup from the lamella clarifier. In spite of this, the results show that the difference in turbidity is highly significant ($p < 0.01$), and differences in colour and pH were also significant. Colour removal is positive (but small) in the lamella clarifier, and generally negative (colour formation) in the existing clarifiers. There is a consistent difference in the pH value, with the lamella clarifier syrup value 0.2 to 0.3 units higher; this taken together with the colour formation in the conventional clarifiers is evidence of degradation reactions occurring in the longer residence time. Purity differences are not significant in view of the variations in the data. The difference in brix values is unexplained; the factory believed it might be due to more evaporation in the existing clarifiers because of the long retention time, or differences in saccharate and flocculant dosage.

The differences were continued to be measured in period 4, over 20 days. In this period turbidity removal in the lamella clarifier and that calculated from the total clarified syrup were 79.7% and 72.7%, respectively. Colour removal was positive, but marginally higher with the lamella clarifier. On liquidation, no blockages or deposits anywhere in the clarifier were observed. Access to the clarifier is easy and is easily drained and washed out.

**JUICE CLARIFICATION**

In applying the approach used in water purification to clarifying sugar juice, the particular properties of the system need to be considered:

- The temperature is much higher, so the use of plastic lamellas is not possible;
- The solids loading is considerably higher, and some of the particles from soil delivered with the cane are significantly larger;
- Most water clarifiers use a lamella slope angle of 50 to 55°. For juice it is probably safer to use 60°.

The particular features of the new design lamella juice clarifier are:

- Circulation patterns are eliminated in the confines of the lamella passages;
- Entering the clarifier, the feed flows down the outside of the banks of lamella plates. This gives the larger particles the possibility to pass straight to the mud cone without entering the lamella passages;
- Juice feed enters the lamellas through the sides of the bank, and not from the bottom, thus not interfering with the passage of settled mud dropping from the bottom of the lamella passages;
- A mud stirrer is unnecessary and so the clarifier has no moving parts and no wear problems, reducing maintenance time and costs;
- Juice retention times, in comparison with a conventional clarifier, are reduced thus minimising juice degradation;
- Low retention times reduce the heat loss in the clarifier, ultimately creating a more energy efficient process.

The design process was unusual, in that the clarifier was designed and installed without the benefit of pilot plant trials, so optimization of the design, in particular establishing the maximum throughput rate, was not possible.

**Plant description**

A lamella juice clarifier sized to initially process 300 t/h of juice feed has been installed in the TPC sugar mill in Tanzania. This clarifier has 92 installed lamella plates with the ability to install an additional 40 plates for a planned future expansion. The lamella plates are set out in two banks with 1.5 m wide plates. The volume of the juice inlet distribution section plus...
the lamella plate section amounts to 20 m\(^3\), while the volume of the mud cone is 43 m\(^3\), which is roughly double the size it would normally be as the cone has been sized for the final expanded operating capacity of the clarifier (Fig. 4). The lamella clarifier has been installed in parallel with an existing 220 m\(^3\) Rapidorr clarifier, with the juice leaving the flash tank being able to be sent either in parallel to both or separately to either of the two clarifiers.

![Fig. 4. View of the TPC juice clarifier.](image)

The design surface load rate for the lamella is 22 m/h over the total plan area of the clarifier and 32 m/h over the lamella settling area which gives a nominal juice retention time of just 5.8 minutes. The nominal retention time based on the total volume of the clarifier is 12.7 minutes. In comparison, the TPC Rapidorr is currently operating at a nominal juice retention time of 57 minutes.

Operational experiences

The TPC lamella clarifier was commissioned in mid-December 2015 and was operated intermittently once installed and then more regularly towards the end of the TPC milling season in early March 2016. The clarifier has been able to produce good quality clarified juice. However, in common with the experiences of many other factories that have converted from operating with clarifiers of long to short retention times, there have been initial problems with the factory adapting to the more stringent requirements that the shorter retention places on ensuring the juice preparation treatment conditions (especially juice temperature) are correct and on managing mud withdrawal and mud levels.

At TPC the Rapidorr clarifier has been regularly operated with juice temperatures entering the flash tank below 98°C and very often even as low as 90°C, and with these conditions, there is excessive mud carry-over from the lamella clarifier. The Rapidorr was used as a mud storage buffer by allowing mud levels to rise while periodic, and often long, operational problems at the mud filter station were being attended to.

While the juice preparation problems were reasonably quickly sorted out the problem of controlling mud withdrawal and mud levels in the lamella clarifier has been far more difficult to resolve. The main reason for this is that the mud surge capacity in the TPC filter station is low, as there is no mud buffer or overflow storage tank. The only surge capacity is in the mud mixer which is very small, having a holding volume of just 1.75 m\(^3\), which represents only a little over 2 minutes of retention at the current factory production rates. Moreover, since the level fluctuations can only be permitted in the space
above the paddle shaft, the actual surge volume amounts to only around a third of the total giving just a 40 second buffer time. In addition, a large capacity Warman centrifugal pump is used for mud withdrawal from the lamella clarifier which makes it difficult for the operating staff to properly regulate the rate of mud withdrawal. These problems have meant that the lamella clarifier mud withdrawal has fluctuated from being too quick, causing weak mud to be delivered to the filters, or being too little, causing the mud level to rise too quickly which can then result in mud carry-over to the clarified juice. These problems with either too quick or too slow mud withdrawal have caused periodic rat-holing in the lamella clarifier mud layer allowing weak mud and juice to pass while heavier mud remains behind. The provision of a better means for regulating the lamella clarifier mud withdrawal and greater surge capacity in the filter station will be addressed during the milling off-season.

On liquidating, no build-up on the internal plates was observed. Some mud build-up in the valley angles initiated at the square-to-round transition at the bottom of the mud boot was evident. This will be remedied in the off-crop, but future designs will have a conical mud boot.

### Settling rate measurements and flocculant dosage

Due to initial problems with juice heating and flocculant addition, initial settling rate values as low as 90 mm/min were measured. Further settling rate measurements conducted at TPC indicate settling rates of around 115 mm/min achieved at a flocculant dosing rate of 32 mg/kg DS (brix) at a 0.15% flocculant strength. This settling rate is lower than the anticipated settling rate of 150 mm/min.

It is anticipated that the more efficient settling performance of the lamella clarifier could result in a reduced flocculant requirement. However, during this initial operational period the focus has been on addressing the problems described above and therefore it has been a conscious choice to err on the side of caution with regard to ensuring adequate flocculant addition and so far no attempt has yet been made to optimise the dosing rate to the lamella clarifier.

### Lamella clarifier juice clarity and turbidity performance assessment

Towards the end of the TPC milling season a test was conducted running both the lamella and Rapidorr clarifiers together with a 50/50 split of the juice flow. With these conditions the juice retention time in the Rapidorr will have been around 5 to 6 times higher than in the lamella clarifier. During this test period the clarity and turbidity of the clarified juice leaving both clarifiers and the total juice were measured. The juice turbidity was measured by the ICUMSA Method GS7-21 and juice clarity was assessed using a clarity wedge (where the higher readings represent greater juice clarity). Some overall comparative results are shown in Table 2, and a graphical illustration of the comparative clarity wedge values showing the variations occurring in practice is presented in Figure 5. A similar pattern was shown by turbidity measurements.

These results show that the lamella clarifier is able to consistently produce a better quality juice in terms of clarity and turbidity.

### Table 2. Comparisons of juice clarity and turbidity.

<table>
<thead>
<tr>
<th>Date</th>
<th>Clarity Wedge readings of clarified juice leaving</th>
<th>Turbidity of clarified juice leaving</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lamella clarifier</td>
<td>Rapidorr clarifier</td>
</tr>
<tr>
<td>27-Feb-16</td>
<td>17</td>
<td>11</td>
</tr>
<tr>
<td>28-Feb-16</td>
<td>14</td>
<td>11</td>
</tr>
<tr>
<td>29-Feb-16</td>
<td>17</td>
<td>11</td>
</tr>
<tr>
<td>01-Mar-16</td>
<td>16</td>
<td>14</td>
</tr>
<tr>
<td>Test Average</td>
<td>16</td>
<td>12</td>
</tr>
</tbody>
</table>
Tracer tests

In order to assess the flow characteristics of the TPC lamella clarifier, a tracer test was undertaken using salt as a tracer, measuring the conductivity of the juice and the mud leaving the clarifier. The salt solution was added over a period of less than 2 minutes, to approximate a pulse input. The tracer test was undertaken with a flow rate of 235 m$^3$/h. The results are shown in Figure 6.

The juice response was not amenable to modelling because of the uncertainty in the base line over the test period. Nevertheless, it does show an average juice residence time of about 8 minutes, compared with an estimated juice residence time of 7.4 minutes, based only on the volume in the lamella area (excluding the volume below the lamellas), or 16.4 min based on the total volume.
The tracer concentration was also measured in the mud leaving the clarifier. It shows a well-defined peak at about 28 minutes with no evidence of a long tail. This is much lower than from other types of clarifier, a big advantage, and under steady conditions the mud filtered easily on the rotary filters.

OTHER OPPORTUNITIES

Press water

One of the disadvantages of diffusion is that less sand is extracted into the raw juice, and more goes to the boiler. This is made worse by the fact that sand extracted in the dewatering mill is recycled to the bagasse entering the mill. One of the ways to obviate this problem is to remove sand from the press water. This is an easy separation, since the settling velocity of sand is of the order of ten times that of mud in a juice clarifier. The objective is not to obtain a clear press water, but purely to remove sand. This is a good application for a lamella clarifier since the unit is small with a low residence time. However, it is necessary to install a juice screen ahead of the clarifier to remove pieces of bagasse which might choke the liquid passage ways.

An analysis of sand removal is possible assuming that 33% of ash is removed into the raw juice from a milling tandem, and 10% from a diffuser. It is also assumed that the percentage removal of sand from each mill is the same. The calculated results are given in Table 3.

<table>
<thead>
<tr>
<th>Process</th>
<th>Sand to last mill</th>
<th>Sand to boiler</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milling</td>
<td>0.819</td>
<td>0.870</td>
</tr>
<tr>
<td>Cane diffusion</td>
<td>1.100</td>
<td>0.900</td>
</tr>
<tr>
<td>Cane diffusion with PW clarification</td>
<td>0.900</td>
<td>0.737</td>
</tr>
<tr>
<td>Bagasse diffusion</td>
<td>0.900</td>
<td>0.737</td>
</tr>
<tr>
<td>Bagasse diffusion with PW clarification</td>
<td>0.737</td>
<td>0.603</td>
</tr>
</tbody>
</table>

A press water clarifier can substantially reduce the problem of sand in bagasse, particularly useful with older multi-pass boilers with high gas velocities.

Phosphatation

Subsequent to running the clarifier at San Antonio as a syrup clarifier, it was run as a phosphatation clarifier in their white end refinery. A comparison is shown in Table 4 of results for the first 20 days of March 2016 running with the conventional clarifier, and results from the following week on the lamella clarifier.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Feed liquor</th>
<th>Clarified liquor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conventional</td>
<td>Lamella</td>
</tr>
<tr>
<td>Brix</td>
<td>67.7</td>
<td>65.6</td>
</tr>
<tr>
<td>pH value</td>
<td>6.2</td>
<td>6.1</td>
</tr>
<tr>
<td>Colour, IU</td>
<td>850</td>
<td>1049</td>
</tr>
<tr>
<td>Turbidity, IU</td>
<td>182</td>
<td>143</td>
</tr>
<tr>
<td>Colour removal, %</td>
<td>32.5</td>
<td>33.9</td>
</tr>
<tr>
<td>Turbidity removal, %</td>
<td>55.1</td>
<td>64.8</td>
</tr>
</tbody>
</table>

The conventional clarifier has a volume of 23 m³ and cannot be run at more than 50 m³/h. The lamella clarifier with a total volume of 5.5 m³ is able to run at a higher flow rate, up to 70 m³/h without problems. It is also reported to be able to operate with less saccharate dosing to achieve the same pH in the clarified liquor and the inlet stream needs to be heated only to 86°C compared to 92°C with the conventional clarifier, because of the lower heat loss.
CONCLUSIONS

Practical full-scale experience with juice, syrup and liquor clarification in lamella clarifiers has shown that they can provide superior performance with very substantial reductions in liquid residence times. This has implications for reduced capital and operating costs and lower sugar degradation losses in process. It is anticipated that this type of equipment can have a major effect on clarification processes in sugar production.

ACKNOWLEDGEMENTS

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REFERENCES


Performance des clarificateurs lamellaires pour le jus et sirop

Résumé. Une nouvelle conception de clarificateur de sirop et de jus est présentée. La conception tire avantage de la performance considérablement améliorée des clarificateurs incorporant des plaques lamellaires, et les raisons de ces améliorations sont décrites. Une simulation numérique de la mécanique des fluides (CFD) de la performance est présentée. La simplicité de la conception permet un temps de séjour considérablement réduit, un coût de fabrication moins onéreux et une meilleure clarification. L’expérience décrite à échelle industrielle confirme les bonnes vitesses d’écoulements. Les résultats des travaux préliminaires sur un clarificateur de sirop à échelle industriel sont présentés et confirme les bonnes dispositions d’opérer comme un clarificateur à phosphatation. En outre, l’évaluation de la performance du clarificateur à échelle industrielle est comparée à celle d’un clarificateur type Rapidorr. Cette étude confirme les avantages considérables que ce type de conception offre dans la réduction significative du temps de séjour, des couts d’investissements et des coûts d’opérations.

Mots clés: Clarification, jus, sirop, liqueur, clarificateur lamellaire, efficience

Desempeño de los clarificadores lamella en jugo y meladura

Resumen. Se presenta un nuevo diseño de clarificadores para jugo y meladura. El diseño toma ventaja de la considerable mejora de desempeño de los clarificadores al incorporar placas lamella, y las razones para esta mejora están descritas. Se resume un estudio de dinámica de fluido por computadoras hecho para simular el desempeño de este sistema de clarificación. Este diseño permite reducir dramáticamente el tiempo de retención y su simplicidad conduce a una mejor y más económica clarificación. Se describe la experiencia en la práctica con unidades a escala fábrica, confirmando las buenas características del flujo. Se presentan resultados de pruebas preliminares hechas en un clarificador de meladura en fábrica, el cual también opera eficientemente como clarificador de fosfatación. Adicionalmente, el desempeño de un clarificador de jugo a gran escala ha sido evaluado y comparado con el desempeño de un clarificador Rapidorr. El presente trabajo confirma las considerables ventajas que este tipo de diseño el cual proporciona substanciales reducciones en tiempo de residencia, costos de capital y costos operativos.

Palabras clave: Clarificación, jugo, meladura, licor, clarificador lamella, eficiencia