Direct clear juice: a summary of experiences gained in the production of clear juice in a sugarcane diffuser

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Abstract The term ‘Direct Clear Juice’ (DCJ) refers to the production of clear juice (CJ) within a modified sugarcane diffuser, thus negating the need for further juice purification in a settling clarifier. The feasibility of producing CJ by filtering treated diffuser juice through a shredded cane bed was demonstrated on a laboratory scale at the Sugar Milling Research Institute NPC (SMRI) and reported at the 2013 ISSCT congress. Factory trials were subsequently conducted at Tongaat Hulett’s Maidstone factory where the promising laboratory results were replicated in a full-scale diffuser. The production of DCJ requires consideration of the juice flow path in the diffuser, the method of lime and flocculant addition, and the screening of the juice after the diffuser. This paper summarises the results and learnings from the DCJ trials between 2011 and 2015. The development of the DCJ technology has been a collaborative project between the SMRI and Tongaat Hulett Sugar.

Key words Clear juice, shredded cane bed, diffuser, factory trials

INTRODUCTION AND HISTORY

In a conventional diffusion factory, suspended solids (SS) and other impurities are removed from draft juice (DJ) by addition of lime and flocculant before solids separation in a settling clarifier. Thereafter, the juice, now termed clear juice (CJ), undergoes evaporation and crystallisation to produce raw sugar. In a DCJ factory, impurities are removed from the juice directly in the diffuser, such that the DCJ leaving the diffuser is suitable for further processing without requiring additional purification. In this process, lime and flocculant are added to the circulating juice in the feed end of the diffuser.

The idea of producing CJ in a sugarcane diffuser is not new, with the earliest mention in literature by Payne (1965). The main problem associated with the early trials was the reduced percolation rate as a result of flocculated mud particles causing blinding of the diffuser bed. The location of lime addition was moved from within the diffuser to before the shredder to distribute the lime within the bed during shredding; this was to try to facilitate the flocculation of mud particles within the bed rather than as a blinding layer on its surface. However, high colour formation resulted from the undiluted lime directly contacting the bagasse fibres. The trials were apparently stopped because no solution for simultaneously overcoming reduced percolation rates and increased colour formation was discovered.

Flooding was a common occurrence in most diffusers, until the invention of lifting screws in the late 1960s. There are no historical records of DCJ trials being performed in a diffuser containing lifting screws. Since the establishment of mud recycling to the diffuser in 1998 in the South African industry, the shredded cane bed has proved itself as an efficient filter of mud solids, and lifting screws have shown their ability to distribute mud particles within the bed such that percolation rates are not reduced. This has raised the question of whether, under the right circumstances, these solids could be flocculated and filtered directly in the diffuser, thus bypassing the need for settling clarification.

The advantages of a DCJ factory, described by Jensen (2013), include reduced equipment, steam consumption and sucrose loss. These advantages, mainly a result of eliminating clarifier heat losses and sucrose inversion, are only realised if the clarifier is bypassed altogether. The annual operational saving of a DCJ factory over a conventional 300 t cane per hour (tch) sugar factory was calculated to be about USD 400 000 per year.

LABORATORY TRIALS

The results of DCJ trials performed in a cane-filled glass column at the SMRI were reported by Jensen (2013). Heated and limed mixed juice (MJ) was circulated through a bed of shredded cane and the clarity of juice exiting the column was...
monitored. It was found that within about 9 minutes of filtration, the turbidity, colour and pH of the circulating juice were all similar to those of conventional CJ leaving a settling clarifier. Mud particles were visibly trapped within the top 200 mm of the 700 mm deep cane bed. The percolation rate through the bed was four times lower than before lime and flocculant addition as a result of the mud layer formed. Upon agitating the bed (simulating the action of lifting screws in a diffuser), the percolation rate increased back to typical column percolation levels.

FACTORY TRIAL – DIFFUSER MODIFICATION

Based on the promising results of the laboratory trials, it was decided to progress to full scale trials. Tongaat Hulett Maidstone factory’s diffuser was modified so that it could be operated in either conventional mode, or DCJ mode. A schematic diagram of the 9 m wide Maidstone diffuser (Tongaat Hulett design) in conventional, counter-current mode is shown in Figure 1.

![Fig. 1. Schematic diagram of Maidstone diffuser in counter-current mode.](image1)

The modification required the addition of pipes and valves to the feed end of the diffuser so that the juice could be circulated co-currently (in the direction of the cane bed movement) above the first two stages in the diffuser. Lime and flocculant pipes were routed to the diffuser; the addition of lime and flocculant raises the juice pH, and facilitates the agglomeration of suspended solids which are subsequently filtered by the shredded cane fibres.

The co-current configuration allows the juice exiting the DJ tray to be re-heated, dosed with lime and flocculant, and filtered through the cane bed (Fig. 2). Draft juice (now termed DCJ) is removed from the diffuser from stage 1 rather than from the DJ stage.

![Fig. 2. Schematic diagram of Maidstone diffuser in DCJ mode.](image2)
TRIAL RESULTS

The full scale trials were conducted at intermittent times during the 2013 and 2014 seasons. A more detailed analysis of the results, including the analytical methods and statistics used, can be found in previous publications (Jensen et al. 2014, 2015). The important DCJ process parameters which were monitored were turbidity, colour, pH, temperature, extraction, and bagacillo contamination.

Turbidity and colour

Juice turbidity and colour are both affected by a number of factors which include cane variety, pH, temperature, time of harvesting, and environmental conditions. These should all be considered when testing the effect of process changes on juice quality. The purpose of the DCJ trials, however, was to see whether juice of similar quality to ‘typical CJ’ (i.e. within the norms of what would be considered acceptable) could be produced without using a settling clarifier, and therefore these confounding factors were not considered.

Turbidity is a measure of the clarity of the juice. It manifests as ‘cloudiness’ and most turbidity measurement techniques are based on the amount of light transmitted through the juice. While any suspended solids which are present in the juice will increase its turbidity reading, the larger particles (>100 μm) tend to settle and thus have less effect on the reading. Turbidity is, therefore, mostly an indicator of the concentration of small particles (<100 μm) which includes proteins, waxes and starch, all of which are in the colloidal size range (0.001-1 μm). Three different methods of assessing juice turbidity were used; online absorbance (using the SMRI’s turbidity meter), SASTA method (Anon. 1985), and clarity wedge. The results in Table 1 show that there was no substantial difference between the turbidity of conventional CJ and DCJ.

<table>
<thead>
<tr>
<th>Method</th>
<th>2011 (laboratory)</th>
<th>2013 (factory)</th>
<th>2014 (factory)</th>
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<tbody>
<tr>
<td></td>
<td>CJ</td>
<td>DCJ</td>
<td>CJ</td>
</tr>
<tr>
<td>Wedge Turbidity (higher is clearer)</td>
<td>14(9)</td>
<td>-</td>
<td>10(73)</td>
</tr>
<tr>
<td>SASTA turbidity (lower is clearer)</td>
<td>9000(14)</td>
<td>10300(6)</td>
<td>6100(6)</td>
</tr>
<tr>
<td>Online absorbance (lower is clearer)</td>
<td>1.2(13)</td>
<td>1.0(13)</td>
<td>0.6(39)</td>
</tr>
</tbody>
</table>

Note: The SASTA turbidity of untreated draft juice is about 23000

Table 2 compares the ICUMSA colour (Anon. 2005) of DCJ with that of conventional CJ. An increase in juice colour was one of the concerns of the trials recorded by Payne (1965), and, therefore, is of importance. While the 2011 results may raise concerns of a colour increase, it must be noted that the CJ was sampled from the factory at the same time that the shredded cane was collected for the laboratory trials. The CJ and DCJ being compared therefore did not originate from the same cane consignment. The 2013 factory trials suggest there is no difference in colour between CJ and DCJ.

<table>
<thead>
<tr>
<th>Method</th>
<th>2011 (laboratory)</th>
<th>2013 (factory)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CJ</td>
<td>26000(6)</td>
<td>27700(6)</td>
</tr>
<tr>
<td>DCJ</td>
<td>30200(6)</td>
<td>27100(26)</td>
</tr>
</tbody>
</table>

Lime addition and pH control

While controlling the pH of DCJ was simple to achieve on a laboratory scale, it was more challenging in the factory. The percolation rate in laboratory trials was typically more than double that in the factory, while the bed depth was about half; the time taken for the juice to pass through the bed was therefore four times longer in the factory. Lime was added to the juice above the cane, while the pH of the juice exiting the bottom of the bed was measured. The retention time between the lime dosing point and measurement point was about 3 minutes in the laboratory, versus about 12 minutes in the factory. A 12 minute dead time between the dosing point and measurement point is not ideal for good control. Despite this
challenge, using an appropriate control strategy, the pH was controllable to within 0.2 pH units of the setpoint for extended periods of time. Multiple lime dosing points and pH measuring points are recommended to improve the quality of control and alleviate the problems with the dead time.

Temperature

In a conventional, counter-current diffuser, cane at ambient temperature is heated by scalding juice at 90°C being poured onto it. The DJ exiting the cane at the front of the diffuser is at about 65°C. The rest of the diffuser must be maintained above 75°C to control microbial activity and promote extraction (Rein 2007); usually 85°C is targeted. In a DCJ diffuser, the juice exiting the front of the diffuser at 65°C is re-heated, treated with lime and flocculant, and returned to the surface of the cane bed. The juice leaves the diffuser from the DJ tray at a temperature above 70°C. Finding the optimum DCJ temperature was one of the goals of the trials. Starch and protein both cause turbidity in the juice, and their removal is affected by temperature. Starch granules are gelatinised above 70°C, rendering them available for breakdown by enzymes which exist in the cane (Rein 2007). Protein is denatured at higher temperatures, and plays an important role in the flocculation process (Rein 2007). Arnold (1996) showed that not all protein in juice is denatured, even above 76°C, and thus a DCJ temperature of about 80°C was targeted.

In the laboratory, it was observed (Jensen 2012) that the juice clarity was noticeably lower when the DCJ temperature was below 70°C. In the first factory trials (Jensen et al. 2014) adequate quality DCJ was produced at temperatures as low as 70°C, but increasing the temperature to around 80°C generally produced a clearer juice. This trend was confirmed in subsequent trials (Jensen et al. 2015), where at 79°C the juice was substantially clearer than at 72°C. A DCJ diffuser requires more heating surface area than a conventional diffuser to achieve the high DCJ temperatures, but the overall factory heating surface area requirement remains unchanged.

Extraction

The purpose of a diffuser is primarily to extract as much sucrose as possible from the cane. Compromising extraction to perform clarification within the diffuser is therefore counter-productive. There are two main reasons why DCJ might reduce the level of extraction in a diffuser: firstly, through the combination of the front two stages in the DCJ section (thereby shortening the counter-current juice flow path), and secondly, due to the possible reduction in percolation rate from the addition of lime.

Extraction was estimated by measuring the amount of sucrose (pol) in the bagasse leaving the diffuser: a higher pol % bagasse is indicative of poorer extraction. The pol % bagasse (hourly samples) for two consecutive crushing weeks, one in DCJ mode, and one in normal mode, are compared in Table 3.

Table 3. Throughput and pol % bagasse data for consecutive weeks in 2014, one in DCJ mode and one in normal mode (no. of samples shown in brackets).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Week 1 (DCJ mode)</th>
<th>Week 2 (Normal mode)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average throughput (tch)</td>
<td>183</td>
<td>186</td>
</tr>
<tr>
<td>Average pol % bagasse</td>
<td>0.94(104)</td>
<td>0.93(125)</td>
</tr>
</tbody>
</table>

The brix profile in a diffuser also gives an indication of the extraction performance. Figure 3 shows eight diffuser profiles: three when operating in normal (CCJ) mode, four from DCJ mode operation, and one (‘mix’) from a day where the front three trays were connected in ‘parallel’, allowing the draft juice pumps to remove juice simultaneously from any of the front three trays. The brix profiles were very different for the front five stages of the diffuser, but thereafter quite similar.
Fig. 3. Maidstone diffuser brix profiles (Jensen et al. 2014) measured under different diffuser configurations.

High extraction levels are expected when the brix at the back of the diffuser (tray 12) is low. Figure 3 shows that the front end configuration does not seem to be the main factor determining the brix % in the juice at the back of the diffuser.

There are a number of possible reasons why extraction was unaffected when running in DCJ mode:

- Neither cane preparation, fibre residence time and imbibition, the three main factors affecting extraction, were changed;
- The juice flow in the front of the diffuser is normally fairly mixed anyway, rather than being counter-current;
- As predicted from the laboratory trials (Jensen 2012), the lifting screws effectively distributed the mud within the cane such that percolation rate was not compromised by running in DCJ mode; and
- The diffuser was not running at maximum capacity.

Bagacillo in juice and options for its removal

The DCJ produced in laboratory trials contained no observable bagacillo particles, whereas some particles were observed in DCJ produced in the diffuser. It is suspected that the continuous interaction between the dragging of the cane bed across the diffuser screen results in some small particles becoming ‘dislodged’ from the cane bed and penetrating the screen. The quantity of bagacillo was measured by filtering a sample of DCJ through a 300 mesh (53 μm) screen (bagacillo particles are generally larger than 100 μm), drying the bagacillo, and expressing the mass as ppm on juice. The average bagacillo contamination found in DCJ was 83 ppm, but needs to be reduced to below 10 ppm to meet direct consumption sugar norms (Jensen et al. 2014).

Fig. 4. Particle size analysis for bagacillo screened from diffuser juice using a 53 μm sieve.
Sixteen particle size analysis tests (using stacked sieves) were performed on the dried bagacillo screened from diffuser juice, with the results shown in Figure 4. It can be seen that 95% of the bagacillo collected on the 53 μm sieve was larger than 250 μm.

Draft juice screening, using either DSM or rotary screens with ‘large apertures’ (500-1000 μm), is common in many diffuser factories. The screens are located above the diffuser so that screened fibre can fall back onto the cane bed. DJ screening serves to remove large fibres which tend to settle and form clumps in the mixed juice tank. These clumps can cause blockages in the MJ pumps and heaters. Small bagacillo particles are not usually a problem, and actually assist the clarification process (Baikow 1967). Their complete removal before clarification is undesirable, and there is, therefore, no reason to use DJ screens with smaller apertures if they are followed by a settling clarifier. CJ screens with apertures less than 100 μm are sometimes used in factories which are prone to mud carryover. The screened fibre is however not as easily dealt with as that from the DJ screens which is just ‘dropped’ onto the cane bed in the diffuser below.

A DCJ factory has the opportunity of using a fine aperture screen in the place of a large aperture DJ screen, as no further treatment of the already clarified juice is required. A small 80 μm woven mesh screen was tested at Maidstone in 2015 with positive results, and further trials are planned in 2016.

Suitability of DCJ technology for ethanol production

While raising the acidic DJ to a pH of 7 is targeted for sugar production to avoid acid inversion of sucrose, this is not a requirement for ethanol production. Ideally, the juice to be fermented should contain as little suspended solids as possible as well as minimal calcium. Suspended solids can increase in concentration and cause blockage problems in processes which recycle yeast. Calcium is a problem as it causes yeast flocculation which inhibits the fermentation process.

Given that the primary means of clarifying juice in the DCJ process is by filtration through the cane bed, it is possible to use less lime than the conventional clarification process. Jensen (2012) found that just the action of heating and filtration (no lime addition) was able to reduce the juice turbidity to levels comparable with CJ. It is expected that the denatured proteins in the heated juice cause flocculation of fine particles which are then filtered out by the cane fibres. The addition of some lime and flocculant however did improve the clarity of the juice.

A DCJ diffuser with a small amount of lime addition, followed by a fine screening step, is expected to produce a juice well suited for fermentation.

CONCLUSIONS

The idea of producing clear juice directly in a diffuser has been revived over the last few years. Lifting screws, which are now common in diffusers, allow lime to be added to the diffuser without inhibiting percolation. After successful laboratory trials in 2011, Maidstone’s Tongaat Hulett-designed diffuser was modified to enable full scale DCJ trials. Juice with similar colour, turbidity and pH to conventional CJ was obtained directly from the diffuser. No decrease in extraction was observed. The bagacillo concentration in DCJ was unacceptably high at 83 ppm, and this needs to be reduced to below 10 ppm for direct-consumption brown sugar. A screen is, therefore, required to remove these small fibres before the clarifiers can be bypassed, and sugar quality maintained. Apart from the sugar industry, DCJ may have an application in the ethanol industry, where it is desirable to add less lime to the juice, but still remove the bagacillo and other suspended solids. Patent applications for the SMRI’s DCJ technology have been lodged in a number of sugar-producing countries.

REFERENCES


**Jus Clair Direct**: un résumé de l'expérience acquise dans la production de jus clair dans un diffuseur de canne à sucre

**Résumé.** « Jus Clair Direct » (DCJ) est la production de jus clair (CJ) dans un diffuseur de canne à sucre modifié, évitant ainsi la nécessité d'une purification supplémentaire du jus dans un décanter. La possibilité de produire le CJ en filtrant le jus de diffuseur traité à travers le lit de canne schreddée a été démontrée sur une échelle de laboratoire au Sugar Milling Research Institute NPC (SMRI) et présenté lors du Congrès ISSCT 2013. Des essais en usine ont été par la suite entrepris à l'usine de Maidstone de Tongaat-Hulett où les résultats prometteurs de laboratoire ont été répliqués dans un diffuseur à grande échelle. La production de DCJ nécessite l'examen du passage de jus dans le diffuseur, de la méthode d'addition de chaux et de floculant et du tamisage du jus après le diffuseur. Cet article résume les résultats et les enseignements tirés des essais DCJ entre 2011 et 2015. Le développement de la technologie DCJ a été un projet de collaboration entre le SMRI et Tongaat Hulett Sugar.

**Mots-clés:** Jus clair, lit de canne schreddée, diffuseur, essais d'usine

**Jugo Claro Directo**: un resumen de las experiencias obtenidas en la producción de jugo claro en un difusor de caña

**Resumen.** El término Jugo Claro Directo (DC por sus iniciales en inglés) se refiere a la producción de jugo claro (CJ, iniciales en inglés) dentro de un difusor de caña modificado, negando así la necesidad de una purificación posterior del jugo en un clarificador por sedimentación. La factibilidad de producir jugo claro (CJ) mediante filtración del jugo tratado del difusor a través de un colchón de caña desfibrada se demostró, a escala de laboratorio en el Sugar Milling Research Institute NPC (SMRI) y reportado en el Congreso de la ISSCT en el 2013. Posteriormente se realizaron pruebas experimentales en la fábrica de Tongaat Hulett Sugar de Maidstone, en donde se replicaron los promisorios resultados de laboratorio en un difusor a escala comercial. La producción de jugo claro directo (DCJ) requiere consideraciones referidas al paso del flujo de jugo en el difusor, el método de adición de cal y floculante y el tamizado del jugo después del difusor. Este trabajo resume los resultados y los conocimientos obtenidos en las experiencias realizadas de Jugo Claro Directo (DCJ) entre el 2011 y el 2015. El desarrollo de la tecnología de Jugo Claro Directo ha sido un Proyecto de Colaboración entre el SMRI y Tongaat Hulett Sugar.

**Palabras clave:** Jugo claro, cama de caña desfibrada, difusor, experiencias fabriles