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DIRECT CLEAR JUICE – THE PRODUCTION OF CLEAR JUICE IN A SUGARCANE DIFFUSER AT MAIDSTONE FACTORY

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Abstract

The Sugar Milling Research Institute NPC (SMRI) performed pilot scale experiments in 2011 to assess the feasibility of producing clear juice (CJ) directly in a sugarcane diffuser. Based on the promising results of these trials, a conventional, counter-current diffuser at Maidstone factory was modified to allow it to be switched between normal mode and a mode that allowed it to produce clear juice directly (Direct Clear Juice or DCJ mode). The diffuser was run in DCJ mode for a number of days during the 2013 season. The quality of juice from the diffuser was assessed and compared with the quality of conventional CJ from a settling clarifier. This report highlights some of the changes made to the diffuser, the results of the trials, and operational considerations involved with the production of CJ directly from a diffuser.

Keywords: diffusion, clarification, clear juice, mud recycling

Nomenclature and terminology

The modification to the diffuser has enabled the production of a product juice of different characteristics to conventional draft juice. The terms below are used to distinguish between the different types of juice referred to in this report:

DJ Draft Juice (collective name for any product juice from the diffuser).
CCJ Counter-current Juice. DJ obtained with the diffuser in normal mode.
FDJ_2 Filtered Diffuser Juice (two-pass filtration through the cane bed achieved by the configuration of the inter-stage juice piping).
DCJ Direct Clear Juice (FDJ_2 with lime and flocculent added).
MJ The term used for unclarified diffuser or mill juice (a more generic terminology for CCJ).
CJ Conventional Clear Juice (the overflow stream from a settling clarifier).

Other abbreviations used in this report:

AU Absorbance units (online turbidity measurement).
CTS Cane Testing Service (an independent laboratory that analyses factory products for cane payment purposes).

IU ICUMSA units (ICUMSA[1] turbidity measurement).
Ms Maidstone diffuser (one of two diffusers at the Maidstone factory: designed by Tongaat Hulett Sugar).
SS Suspended Solids.
THS Tongaat Hulett Sugar.
Tg Tongaat diffuser (one of two diffusers at the Maidstone factory: designed by BMA[2]).
WU Wedge Units (wedge clarity measurement).
PR Percolation Rate (the flowrate of juice through the cane bed per unit area of the bed).

Introduction and history

While the idea of producing CJ in a sugarcane diffuser is not new, Jensen (2012) showed that the presence of lifting screws in modern diffusers has increased the viability of the process. In a conventional diffusion factory, suspended solids (SS) and other impurities are removed from the draft juice (DJ) in a settling clarifier, before the juice, now termed clear juice (CJ), is concentrated in evaporators. In a DCJ factory, impurities would be removed from the juice directly in the diffuser such that the DCJ leaving the diffuser would be suitable for evaporation with no, or minimal, further treatment required. The advantages of a DCJ factory, described by Jensen (2012), include reduced equipment, reduced steam consumption, and reduced sucrose loss. The Maidstone (Ms) diffuser was modified in 2013 to enable the production of DCJ in the diffuser. As a safety precaution, the clarifiers remained in operation while the trials were in progress. This report highlights some of the changes made to the diffuser, the results of the trials, and operational considerations involved with the production of CJ directly in a diffuser.

Experimental

Maidstone factory has two diffusers: a 6.4 m wide 'Tongaat (Tg)' diffuser (BMA design), and a 9 m wide 'Maidstone (Ms)' diffuser (THS design). Both diffusers were in operation during the 2013 season. A schematic diagram of Ms diffuser in conventional, counter-current mode, is shown in Figure 1.

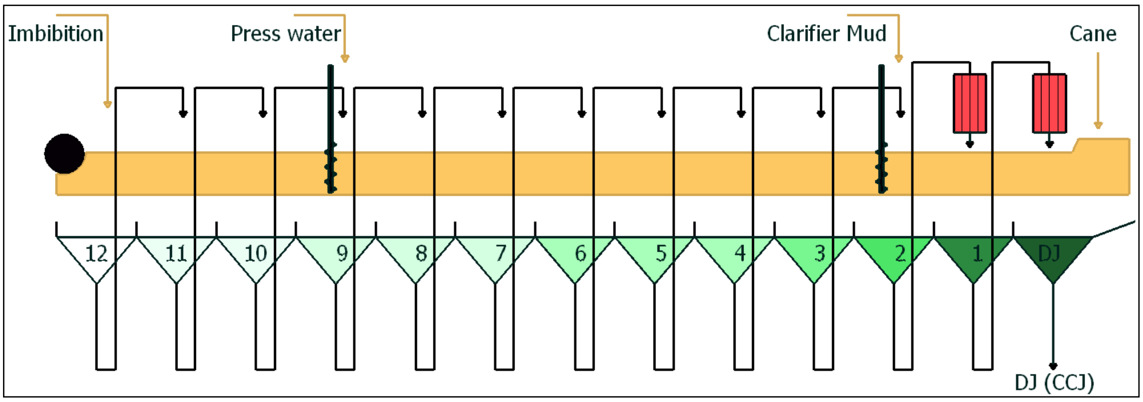

Figure 1. Schematic diagramme of Maidstone diffuser in counter-current mode.

Maidstone factory allowed the SMRI to oversee the reconfiguration of their Ms diffuser in order to test the DCJ process. Figure 2 shows the Ms diffuser configured in DCJ mode.

[1] ICUMSA: International Commission for Uniform Methods of Sugar Analysis
[2] BMA: Braunschweigische Mashinenbauanstalt AG

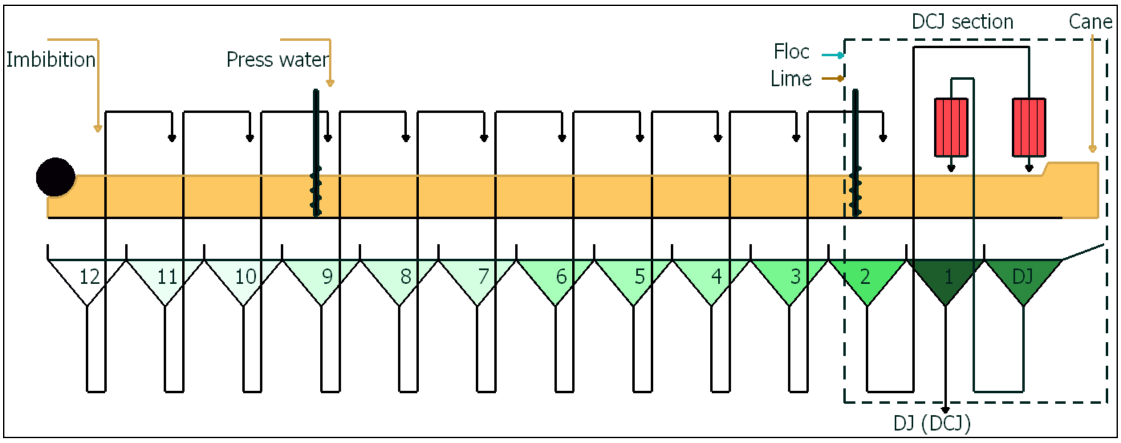

Figure 2. Schematic diagramme of Maidstone diffuser in DCJ mode.

The modifications enabled:

- Lime and flocculant to be added directly to the diffuser, thereby facilitating the agglomeration of suspended solids contained within the juice, and raising its pH.
- The treated juice to be directed through the cane bed co-currently, thereby removing the agglomerated suspended solids from the juice by filtration through the cane bed itself.
- The DJ temperature to be increased from ~70°C for CCJ to ~80°C for DCJ, which facilitates the removal of protein and other organic components from the juice.

At times the diffuser was operated with the DCJ co-current configuration shown in Figure 2, but without the addition of lime and flocculant. The draft juice from the diffuser in this mode was termed FDJ_2.

The initial goal of the trial was to ensure that the reconfiguration did not upset normal factory operations, or increase losses. Only after this goal was achieved could the diffuser be run for extended periods of time in DCJ mode, allowing a comparison between DCJ and conventional CJ.

Methods of assessing juice quality

Sugar quality is the main quality parameter for raw sugar factories. It was not possible to bypass the Maidstone clarifiers when the diffuser was operating in DCJ mode and a comparison of sugars produced from DCJ and CJ was therefore not possible. Instead, it was decided that if the quality of DCJ was similar to that of conventional CJ, then the effect on sugar quality was likely to be negligible. Draft juice contains impurities of differing size and nature, as described in Table 1.

Table 1. Some impurities in draft juice which are partially or completely removed during clarification.

Impurity	Estimated size of impurity
Bagacillo	150 - 1500 μm
Sand	62 - 1000 μm
Silt	1 - 62 μm
Clay	<1 μm
Protein	Colloidal (0.001 - 1 μm)
Pectin	Colloidal (0.001 - 1 μm)
Wax	Colloidal (0.001 - 1 μm)
Starch	Colloidal (0.001 - 1 μm)

The effectiveness of conventional clarification is usually measured by assessing the turbidity (the 'inverse' of clarity) of CJ and comparing it to some expected norms. Given the different nature of impurities in CJ, four different methods were used to get a more complete picture of the quality of DCJ compared with CJ.

(i) Wedge clarity
The 'Buckman' wedge, shown in Figure 3, is graded from 1 at the narrow end to 49 at the wide end. The wedge is filled with juice and the highest visible number (to the naked eye) is recorded as the wedge clarity in wedge units (WU). Bagacillo and sand do not affect the wedge clarity reading.

Figure 3. Buckman wedge for measuring juice clarity.

(ii) ICUMSA colour and turbidity (Anon, 1985)
In the ICUMSA colour method, the juice is first filtered through a 0.45 μm membrane before measuring the amount of light (at 420 nm) absorbed by the juice. The ICUMSA turbidity method measures the difference in absorbance (at 420 nm) between a filtered sample and an unfiltered sample of juice. Tests at the SMRI (see Appendix A) showed that bagacillo and sand (settleable solids) have a negligible effect on the ICUMSA turbidity reading. A confidence range of ±1000 units should be applied to both colour and turbidity to account for analytical inaccuracies based on the findings of Muir (2009).

(iii) Online absorbance

An online absorbance meter developed by the SMRI and marketed by Sugarequip (Pty) Ltd was previously described by Mkhize (2003). A slipstream of the juice to be sampled flows by gravity through the device, and its absorbance is continuously measured on an arbitrary scale between 0 and 4 absorbance units (AU), where 0 is the absorbance of clean water. Bagacillo and sand have a negligible effect on the absorbance reading. While the online absorbance measurement was designed to measure juice quality continuously, regular intervention was required to unblock the sample line to the meter when it became blocked with fibre. Consequently, online absorbance was often used just to measure catch samples of juice.

(iv) Bagacillo screening

As the transmittance methods do not account for the larger suspended solids in the juice, an alternative method was required to assess the amount of bagacillo and sand in the juice. Approximately 160 litres of juice was screened through a 53 μm screen. The fibre filtered by the screens was dried to constant mass, weighed, and the results expressed as both ppm on sample, and ppm on brix. Due to the large volume of juice screened, this method minimises sampling and analytical errors which are difficult to avoid in the CTS method for suspended solids measurement (Anon, 1985).

Data collection

The duration of DCJ testing conducted during 2013 is shown in Table 2. The results are separated into four months (although some September data is included in the August summary) so that seasonal effects could be observed. As operational issues were overcome and confidence in the process increased, the duration of the individual DCJ tests was lengthened. Dosing of lime and flocculant into the diffuser was performed by manually switching on the pumps and adjusting their speeds according to the dosage rate required. Given the attention that this operation required, lime was normally dosed only during the day, when extra personnel were on hand to monitor the dosage. In August, although lime was dosed into the diffuser only during the day, the co-current configuration was not changed during the night. This allowed the effect of configuration alone on factors such as extraction, to be observed. Draft juice produced under this mode of operation was termed FDJ_2. In November, extra personnel were allocated to the night shifts, and the diffuser was operated for up to four days continuously in DCJ mode (before stopping for weekly evaporator cleaning) without any operational problems being observed.

Table 2. Overview of the direct clear juice (DCJ) tests performed at Maidstone in 2013.

Month	Estimated total trial hours	Individual test length
May	30	Day shift only
June	24	Day shift only
August	90	DCJ day/FDJ_2 night
November	95	Continuous DCJ trials

Results

The 2013 season was a difficult one for Maidstone, characterised by a number of breakdowns, inconsistent cane supply, and a large focus on recovering lost throughput, often at the expense of performance. Testing a new technology in this environment and with limited personnel dedicated to the task made an experimental design difficult to follow. It was only in November that extended trials were performed and hourly juice samples collected. Before then, juice was sampled and analysed on an *ad hoc* basis. With the focus of the trials for most of the year being on getting the hydraulics of the DCJ-configured diffuser to work, the analytical data which was collected should not be considered more than ‘incidental’. Statistical analysis of the data was not performed due to the large differences in sample sizes, and the numerous factors which could have affected the results (such as varying cane quality), but were not measured. Nevertheless, the results below provide interesting insight into the capability of the DCJ process.

Online absorbance and wedge turbidity

The mean DCJ and CJ absorbances shown in Figure 4 were observed to be similar. The absorbances of both types of juice increased towards the end of the crushing season when cane quality was generally poor. While not recorded, it was also observed that the turbidity of CJ generally decreased when the diffuser was in DCJ or FDJ_2 mode. It is suggested that the double clarification of the juice was the reason for this. Figure 4 also shows that the clarity of FDJ_2 juice, where lime and flocculant were not added to the diffuser, was not much worse than that of CJ or DCJ. Heating and filtration through the cane bed alone apparently causes a significant reduction in DJ turbidity. This observation is consistent with the findings from Jensen’s (2012) pilot scale DCJ trials. It is suspected that protein coagulation (which is more complete at higher temperatures) and its subsequent filtration is the main reason for this. The wedge clarity results in Figure 5 show similarities to Figure 4. No measurements of wedge clarity for FDJ_2 were recorded. The clarity of CCJ was estimated to be 3 WU, based on a number of unrecorded observations during the season. The data for the graphs in Figures 4 and 5 are given in Appendix B, and the error bars represent the standard deviations for each data point.

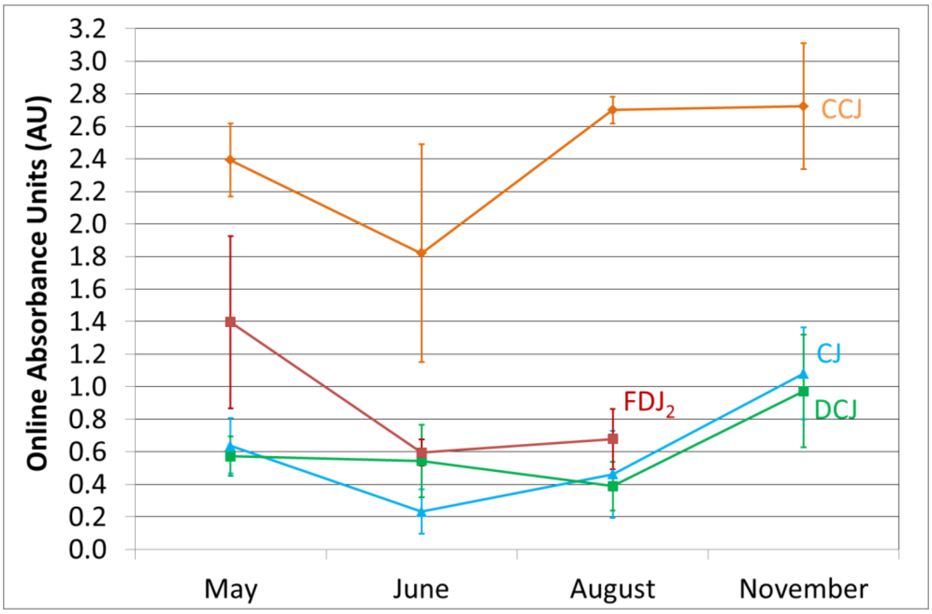

Figure 4. Online absorbance results for 2013 direct clear juice trials (lower values are indicative of clearer juice).

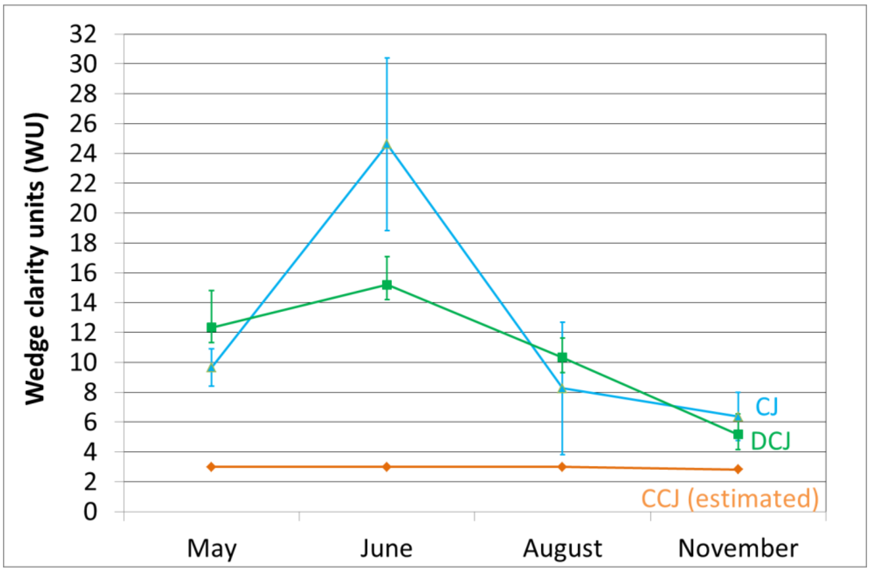

Figure 5. Wedge clarity results for 2013 direct clear juice trials (higher values are indicative of clearer juice).

ICUMSA colour and turbidity

ICUMSA colour and turbidity analyses were performed only during the November trials. Clear juice was sampled with the diffuser in CCJ mode to avoid any double clarification effect. It can be seen from Table 3 that both CJ and DCJ had much lower turbidity than CCJ. Fewer CJ and CCJ samples were analysed than DCJ due to analytical load constraints. While the average CJ turbidity was similar to that of DCJ, its variability appeared higher. None of the 26 DCJ samples analysed were over 10 000 IU, whereas CJ samples above 12 000 IU were occasionally observed.

Table 3. November 2013 ICUMSA turbidity analyses.

	CCJ	CJ	DCJ
No. of samples	4	6	26
Average (IU)	23300	6100	7200
Minimum (IU)	21700	2300	5100
Maximum (IU)	26900	12400	9900
Std. deviation (IU)	2100	3200	1200

Table 4 shows that the ICUMSA colours of CJ and DCJ were similar, and about 14% higher than the CCJ colour. The increase in colour was expected as a result of lime addition to the juice. It is expected that automated lime dosing, which should avoid the higher pH peaks periodically encountered with manual liming, would reduce the formation of colour in DCJ. A more detailed study, taking into account cane quality, is required to gain more insight into the formation of colour during the DCJ process.

Table 4. November 2013 ICUMSA colour analyses.

	CCJ	CJ	DCJ
No. of samples	4	6	26
Average (IU)	24200	27700	27100
Minimum (IU)	22500	26400	22500
Maximum (IU)	25500	28900	29400
Std. deviation (IU)	1200	800	1500

2011 CJ quality from Ms factory

As part of the piloting work performed at the SMRI in 2011, a number of CJ samples from Ms factory were collected and analysed. The results in Table 5 show that in 2011 the average CJ turbidity was 9000 IU, compared with 6100 measured in November 2013 (Table 3). This result is surprising, as the 2011 samples were spread out over the whole season compared with only November in 2013. This highlights the year to year variability in cane quality and/or factory performance.

Table 5. 2011 clear juice analytical results from Maidstone factory.

	Wedge (WU)	Colour (IU)	Turbidity (IU)
No. of samples	9	14	14
Average	14	26000	9000
Minimum	7	22000	2500
Maximum	20	29000	16100
Std. deviation	4	1600	4100

Bagacillo screening

Table 6 shows that DCJ contained about 30 times more bagacillo than CJ. This suggests that filtration through the cane bed alone is unable to remove all the SS from the juice. Very little sand was observed in DCJ. The long (2-3 h) residence time which Maidstone was running through their clarifiers would have contributed to the very low bagacillo levels in CJ. A particle size distribution analysis for bagacillo screened from DCJ (Appendix C) revealed an average particle size of 919 µm.

Table 6. Bagacillo screened from juice at Maidstone in 2013.

	CCJ	CJ	DCJ
No. of samples	5	6	19
Average (ppm)	67	1	34
Minimum (ppm)	13	1	5
Maximum (ppm)	178	2	91
Std. deviation (ppm)	63	1	22

By assuming a brix of 13 for all the juice samples, the bagacillo contamination was estimated on an ‘on brix’ basis (Table 7).

Table 7. Bagacillo screened from juice at Maidstone in 2013.

	CCJ	CJ	DCJ
No. of samples	5	6	19
Average (ppm on brix)	515	9	261
Minimum (ppm on brix)	97	4	41
Maximum (ppm on brix)	1372	16	703
Std. deviation (ppm on brix)	481	4	170

While DCJ contained on average 261 ppm bagacillo on brix, of primary concern is the effect that this will have on the bagacillo levels of raw sugar. There is no general specification for bagacillo contamination in raw sugar in South Africa. Weekly suspended solids analyses were performed for five South African factories throughout the 2013 season, and the averages of these results are shown in Table 8. Smith *et al*. (2000) found that with no syrup clarification (as was the case in all five factories) bagacillo constituted about 73% of the suspended solids in raw sugar, and the average bagacillo level in raw sugar from the five factories was thus estimated to be 77 ppm. Interestingly, factory 1, which packs raw sugar for direct consumption, has the highest SS contamination. Personal communication with another factory revealed that they do not routinely analyse their sugar for SS, and are more concerned with ‘black specks’ than bagacillo.

Table 8: Suspended solids and estimated bagacillo in raw sugar for five factories in 2013.

	1	2	3	4	5	Avg
Suspended solids in sugar (ppm)	206	98	71	50	99	105
Estimated bagacillo in sugar (ppm)	151	72	52	37	72	77

If it is assumed that all the bagacillo in DCJ is ‘caught’ at the centrifugals, either by the screen or by the sugar crystals themselves, then its level in sugar can be estimated as follows:

Bagacillo in DCJ	= 261 ppm on brix
Assumed juice purity	= 84%
Bagacillo in DCJ	= 261/0.84 = 310 ppm on sucrose
Assumed boiling house recovery	= 86%
Bagacillo in raw sugar	= 310/0.86 = 361 ppm on sucrose in raw sugar
Assumed sucrose % raw sugar	= 99.3%
Bagacillo in raw sugar from DCJ	= 361 x 0.993 = 358 ppm on raw sugar

While clearly a worst case scenario, this level of bagacillo contamination (358 ppm) would almost certainly be unacceptable in raw sugar, particularly if it is to be used for direct consumption. The effect of bagacillo contamination on sugar being processed in a refinery is unknown. On one hand it may improve the filterability of sugar by acting as a filter aid, but on the other it may lead to an increase in silica in the refinery, as suggested by Madho and Davis (2011). Two main options are possible for reducing this contamination to acceptable levels. Juice screening (using conventional DSM screens or the more recently popular rotating drum screens, eg. Contrashear) is not performed at Maidstone but is an obvious way to reduce the quantity of bagacillo in the juice. Syrup clarification (as installed at Maidstone) has also been shown to be very effective in removing bagacillo. Smith *et al*. (2000) show that a well operating syrup clarifier can reduce the bagacillo level in treated syrup to around 10 ppm. It appears that either one of or both of these processes would need to be installed to ensure that an acceptable quality raw sugar is made from DCJ.

Observation of clarifier mud level

For most of the season, both diffusers at Ms factory were in operation. During one trial, however, only the Ms diffuser was in operation. The operators were told not to pump any underflow from the clarifiers to the Ms diffuser unless mud levels were observed to be increasing. A number of sample points, protruding from the clarifier wall at different heights, were used to determine the level of mud in the clarifier. The mud level in the clarifiers did not increase for 10 h with Ms diffuser running in DCJ mode. Upon starting the Tg diffuser, the level of mud in the clarifiers was found to increase rapidly. This suggested the effectiveness of the DCJ configured Ms diffuser in retaining mud compared to the conventionally configured Tg diffuser.

Comments and observations from continuous monitoring of juice quality during different trials

In Figure 6 it can be seen that changing the diffuser from FDJ_2 mode to DCJ mode (adding lime and flocculant) reduced the online turbidity from ~0.7 to ~0.3 AU. The wedge clarity increased by ~2 units at the same time. The CJ absorbance was also seen to drop when lime and floc were added to the diffuser. This made simultaneous comparisons between CJ and DCJ difficult, as the CJ clarity improved due to the 'double clarification' effect.

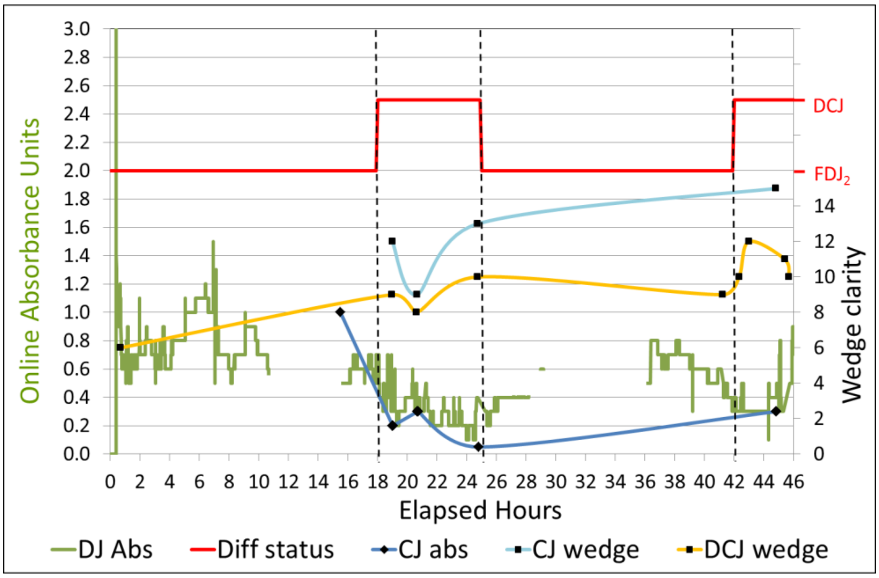

Figure 6. Turbidity monitoring from 27/08/2013 to 28/08/2013.

For the period shown in Figure 7, the diffuser was initially in CCJ mode. In this mode it was difficult to measure the DJ absorbance continuously, as the sample line to the absorbance meter tended to become blocked with fibre. CCJ absorbance is typically 2.5 units, and after switching the diffuser into DCJ mode the turbidity dropped to 0.2 units within three hours. The rate of turbidity decrease is largely dependent on the juice volume in the trays upon reconfiguration. If the trays are empty, the turbidity can decrease from 2.5 units to below 0.7 units within 20 minutes of the reconfiguration, due to the low volume of juice requiring filtration.

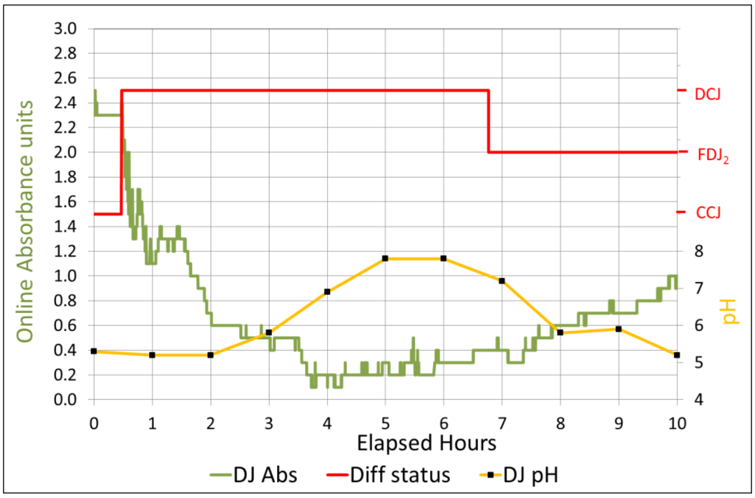

Figure 7. Turbidity and pH monitoring on 03/09/2013.

Figure 8 shows hourly results for the November trials. The DCJ results are shown in section A, DJ (in CCJ mode) in section B, and CJ (with the diffuser in normal/CCJ mode) shown in section C. The targeted DCJ pH was 6.5, and this was controlled by manually adjusting the lime dosing pump based on hourly pH samples from the mill laboratory. It is expected that the variability in DCJ pH could be greatly reduced by automating the lime dosage rate. The DJ pH with the diffuser in CCJ mode was slightly above five, which is typical for untreated cane juice. The factory's CJ pH control, with the diffuser in normal/CCJ mode, was also far from optimal during the hours of monitoring, but the reason for this is unknown. The absorbances of both DCJ and CJ in November were much higher than at other times in the season, but similar to each other. CJ wedge clarity appeared slightly better than DCJ wedge clarity, but both were rather poor, due to the low quality of cane being crushed at the end of the season.

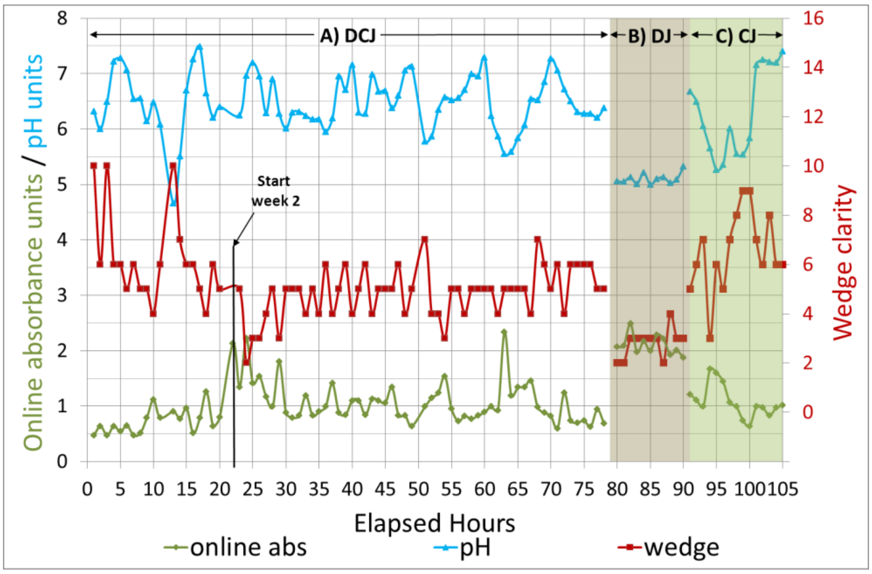

Figure 8: Turbidity and pH monitoring from 14/11/2013 to 22/11/2013.

Effect of DCJ configuration on percolation rate in the middle of the diffuser

One of the concerns with DCJ was the possibility that it might reduce the percolation rate in the diffuser. Jensen (2012) showed that the addition of lime to a pilot scale diffuser reduced the percolation rate due to a layer of mud forming on the surface of the bed. It was, however, discovered that this mud layer could be redistributed within the cane bed by simulating the mixing effect of lifting screws, and the percolation rate subsequently increased to acceptable levels. In order to measure the percolation rate in the Ms diffuser, a level gauge was fitted to tray 5 (Figure 2). By stopping the pump on the outlet of the tray, and measuring the increase in juice level, the flowrate of juice into the tray could be estimated. This flowrate was then converted into a percolation rate by considering the screen area above the tray. A number of spot tests were performed with the diffuser in different configurations, and the results are shown in Table 9. By using the method described by Jensen (2013), the actual amount of juice being recycled (R_{actual}) to tray 5 was calculated (see Appendix D and Table 9). Although percolation rate seemed to increase with lime addition and DCJ configuration, the limited number of tests prevents any definite conclusions from being drawn. The increase in percolation rate may in fact be due to greater recycling of juice caused by a less permeable bed. The maximum percolation rate (MPR) of the bed may have been lowered, even though the percolation rate measured increased. Nevertheless, it did not appear that DCJ had a negative effect on the percolation rate in the diffuser.

Table 9. Percolation rates and juice recycled to tray 5 under different diffuser configurations and throughput conditions.

Configuration	Cane throughput (t/h)	Imbibition % fibre	PR ($m^3/m^2/min$)	R_{actual} (%)
CCJ test 1	170	307	0.08	13
CCJ test 2	170	307	0.09	22
FDJ_2 test 1	170	307	0.10	29
DCJ test 1	170	307	0.11	40
DCJ test 2	178	217	0.12	53
DCJ test 3	193	320	0.12	35

Lime consumption in DCJ mode

Rein (2007) suggests that factory lime consumptions between 0.6 and 1.3 kg CaO/t cane are normal. These values are for the entire factory, but most of this lime is used to neutralise the juice acidity. The lime consumption in DCJ mode was estimated by measuring the lime dosage rate, and the calculations are shown in Appendix E. Table 10 shows that the lime consumption in DCJ mode is similar to the values estimated by Rein (2007) for a conventional factory.

Table 10. Consumption of lime in direct clear juice (DCJ) mode.

Date	Mode	Lime dosing location	Juice pH	kg CaO/t cane
03/09/2013	DCJ	Diffuser SJ pumps	7.3 (DCJ)	0.8
04/09/2013	DCJ	Diffuser SJ pumps	6.5 (DCJ)	0.5

Flocculant dosing

Jensen (2012) found that dosing flocculant to the diffuser in addition to lime improved the clarity of the DCJ produced. A reserve pump, controlled by a variable speed drive, was used to pump flocculant from the MS juice section to the diffuser. The dosage rate was measured by a rotameter, and varied between 3 and 10 ppm on DJ flow, normally as a result of changes in the juice flow rate rather than the flocculant dosage rate. It is not expected that a flocculant rate of more than 3 ppm would be required for DCJ production, but its effect on DCJ turbidity has not been closely investigated. During one trial the mixed flocculant concentration was observed to be very low (judging by its ‘feel’) and upon increasing it to the recommended 0.05%, the juice clarity was qualitatively observed to improve.

Effect of trough levels on DCJ quality

Ideally, juice trays in a diffuser should never fill up and overflow into the adjacent trays. This is usually caused by slowing down the DJ pumping rate as a result of downstream bottlenecks in the factory. The DJ tray overflows into tray 1, which in turn fills up and overflows into tray 2, and so on. In a conventional diffuser, this overflowing of juice from one tray to the next disrupts the brix profile and can lead to lower extraction levels. In a DCJ diffuser, overflowing juice trays were expected to contaminate the ‘clean juice’ with ‘dirty juice’. For most of the trials, between one and five trays in the diffuser were full due to downstream bottlenecks, but the clarity of DCJ obtained was not observed to be qualitatively different to periods when none of the trays were full. During the November trials, the number of full trays in the diffuser was recorded, and Figure 9 shows no clear relationship between absorbance and the number of full trays in the diffuser. While apparently not a requirement, it is still recommended as best practice to operate with minimum juice levels in the trays irrespective of the diffuser operational mode.

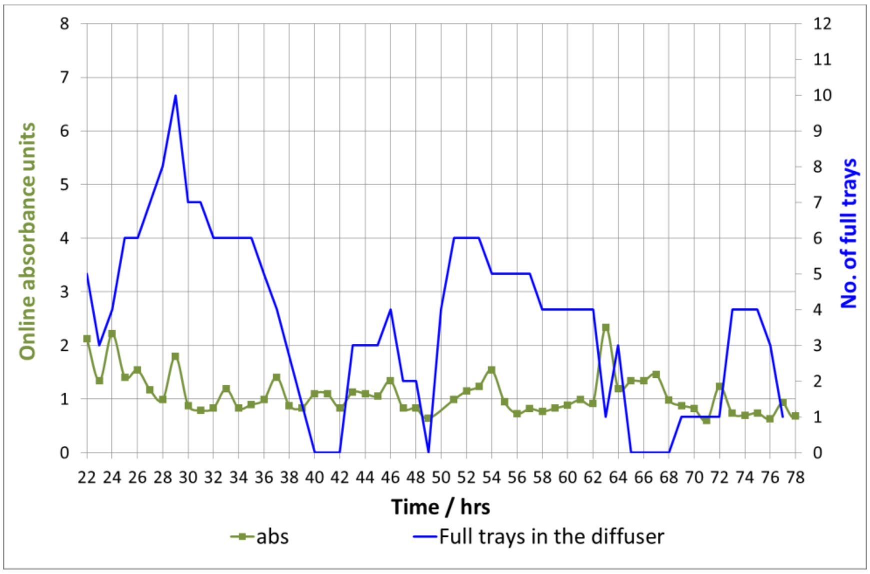

Figure 9. Direct clear juice absorbance and full diffuser trays during the November trials.

Effect of DCJ configuration on extraction

There are two main reasons why DCJ may reduce the level of extraction in a diffuser: firstly, through a reversal in the counter-current flow of juice relative to the cane in the DCJ section of the diffuser and, secondly, due to the possible reduction in percolation rate if lime is added to the diffuser. Pol extraction is calculated only daily at the factory, and is dependent on a number of factors, including cane quality, which fluctuates with periods of much less than one day. Given that many of the DCJ trials lasted only about 8 h, a more frequent assessment on the likely impact of DCJ on extraction was required: two different methods were used for this purpose. The first was a comparison of the daily diffuser brix profiles, and the second the monitoring of the hourly pol % bagasse values measured by the CTS laboratory. Figure 10 shows eight diffuser profiles: three when operating in 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.

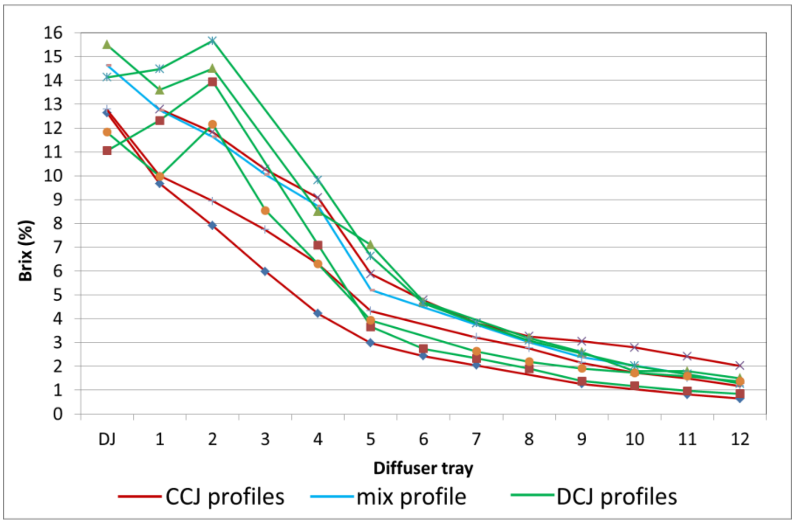

Figure 10. 2013 Maidstone diffuser brix profiles measured under different diffuser configurations.

High extraction levels are expected when the brix at the back of the diffuser (tray 12) is low. Figure 10 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.

Pol % bagasse analyses for a number of days are shown in Figures 11 and 12. As cane throughput (presented as tch/100), moisture % bagasse and imbibition % fibre (Imb/F) can all influence the pol % bagasse, these values are also shown on the graphs. The diffuser mode is represented by the value of the red line labelled 'Diff status'.

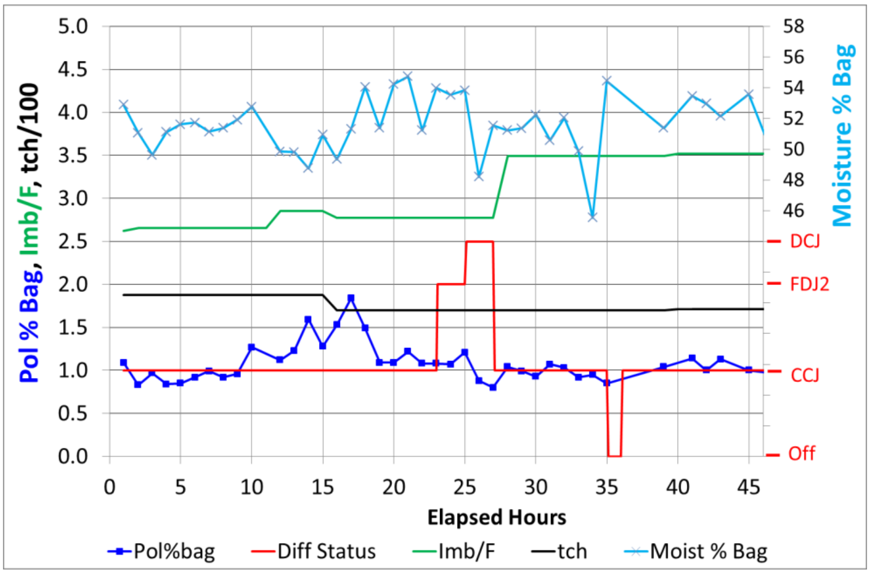

Figure 11. The impact of diffuser configuration on Pol % bagasse from 22/08/2013 to 26/08/2013.

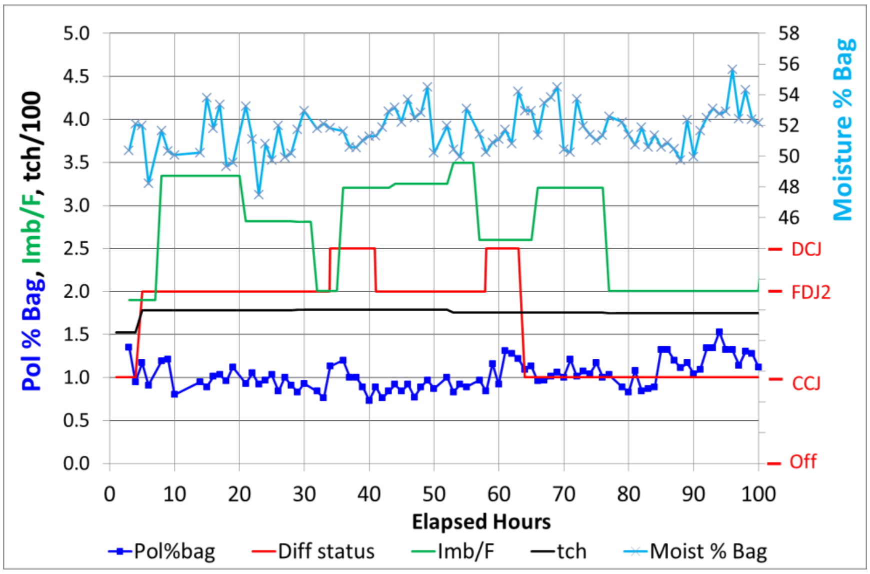

Figure 12. The impact of diffuser configuration on Pol % bagasse from 27/08/2013 to 30/08/2013.

Figure 11 shows no evidence of the diffuser status affecting pol % bagasse values. In Figure 12, although it appears the pol % bagasse may have increased during periods of lime and flocculant addition, these periods are also marked by a decrease in imbibition % fibre, which is the more likely reason for the increase. It should also be remembered that Ms diffuser was never run at more than 180 tch during the trials. It is designed for a throughput of 350 tch and, if DCJ does have a negative effect on extraction, it would be more pronounced at higher throughputs.

Effect of temperature and mud on turbidity

Temperature

During the trials, Ms was experiencing variable steam pressures, which impacted on the temperature in the diffuser. While adequate quality DCJ was achieved with DCJ temperatures as low as 70°C, it seemed that higher temperatures produced better quality juice. This observation is consistent with the findings of Jensen (2012) from pilot scale trials. The maximum DCJ temperatures that were achieved were around 82°C. It is thought that turbidity improved as temperature increased due to the enhanced removal of both protein and starch granules. Starch granules are gelatinised above 70°C, rendering them available for breakdown by enzymes which exist in the cane juice (Rein, 2007). A study by Arnold (1996) showed that not all protein in juice is denatured, even above 76°C. It is expected that the optimum DCJ temperature range would fall between 80 and 85°C. At too high temperatures (bearing in mind the juice in the front stage of the diffuser is always ~65°C due to the cold cane) the enzymes which break down the gelatinised starch would themselves be destroyed. The temperature plot in Figure 13 shows that the temperature in November was seldom above 75°C. There may be something of a mirror image relationship between the temperature and turbidity curves shown in Figure 13, but the suspension of mud recycling to the diffuser is also contributing to this effect.

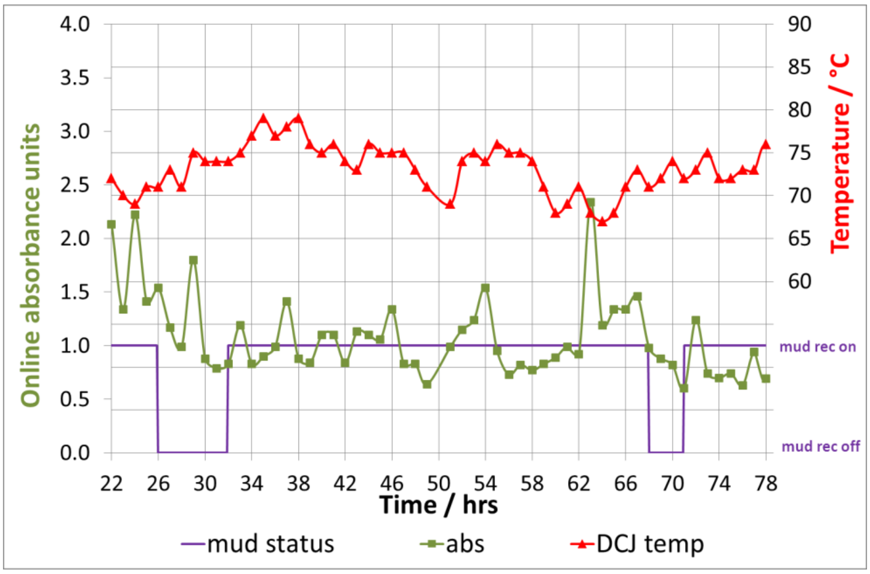

Figure 13. Direct clear juice (DCJ) absorbance with changing DCJ temperature and mud status.

Mud

Clarifier mud is preferentially recycled to the Ms diffuser rather than to the Tg diffuser. The location of mud addition is shown in Figure 1. Even when mud recycling is 'on', mud is pumped intermittently from the clarifiers to the diffuser, so it is difficult to observe the effects of mud addition on DCJ quality. There were, however, some periods during the November trials when mud recycling to Ms diffuser was switched 'off', and it appears from Figure 13 that DCJ turbidity decreased as a result. This could be expected, as the addition of mud to the bed on the 'DCJ side' of the lifting screws could lead to mud solids penetrating through the bed, and ending up in DCJ. In a full configuration DCJ factory, there would of course be no mud to recycle to the diffuser.

Conclusions

The 2013 DCJ trials at Maidstone showed that juice of similar turbidity to factory CJ could be continuously produced in a reconfigured diffuser into which lime and flocculant are added. The following observations were deduced from the results:

- Lime consumption in a DCJ factory is expected to be similar to a conventional factory.
- The quality of DCJ is not highly sensitive to juice levels in the diffuser trays.
- No impact on extraction was observed with up to 180 tch through the 9 m wide diffuser.
- Lime was dosed manually, but the system appears suitable for automatic pH control.
- No reduction in percolation in the diffuser was observed when it was configured in DCJ mode.
- CJ and DCJ turbidities were similar throughout the season.
- If untreated (by juice screening or syrup clarification), sugar from DCJ could contain up to 358 ppm bagacillo versus an average of 77 ppm bagacillo in raw sugar estimated for five South African factories in 2013.

Future trials should focus on:

- Investigating the effects on extraction, particularly with higher cane throughputs.
- Evaluating the effect of DCJ on the start-up and shut-down of the diffuser and factory.
- Monitoring fouling rates in the scalding juice heaters.
- Comparing acetic acid levels in DCJ with acetic levels in CJ.
- Automatic pH control.
- Downstream effects of DCJ, including sugar quality, evaporator fouling and overall recovery.
- Removal of bagacillo from DCJ through juice screening or flotation.

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Trials of this nature normally involve substantial extra effort and unrewarded 'favours' from factory personnel. The authors would especially like to thank: George Govender and Jayce Moodley from Maidstone laboratory for their assistance with juice analysis; Nomusa Nyirenda, Warren Sheahan, Natasha Sharma, Nishan Maharaj, Pride Makhathini and Gugu Mhlongo for their monitoring of the process in the absence of SMRI personnel; Dr Katherine Foxon of the SMRI for her review of the work performed and assistance with the interpretation of results; Dr Craig Jensen of THS for his support and allocation of THS Technology and Engineering Group personnel to assist with the trials.

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APPENDIX A
Effect of Bagacillo of different size ranges on ICUMSA turbidity

A sample of MJ juice was diluted to 5 brix, and its ICUMSA turbidity was measured as the control in Table A1. The control sample was divided into four subsamples, and into each subsample, 200 ppm of bagacillo (of different sizes) was added. The turbidities of the samples were then measured:

- by recording the absorbance as soon as the sample was added to the spectrophotometer.
- by recording the absorbance once the spectrophotometer reading had stabilised after 15 seconds.

The purpose in the two turbidities measured for each sample was to assess whether giving the SS a chance to settle in the sample vial would change the absorbance reading. It is expected that most of the SS had settled anyway by the time the initial reading was taken. It was thus concluded that bagacillo has minimal effect on ICUMSA turbidity readings.

Table A1. ICUMSA[3] turbidities of juice contaminated with 200 ppm of bagacillo of various sizes.

Bagacillo particle size	Initial T (IU)	Final T (IU)
Control	15100	
Below 250 µm	16300	15500
250 - 500 µm	15300	15200
500 - 850 µm	17700	16000
850 - 1000 µm	13441	12555

[3] International Commission for Uniform Methods of Sugar Analysis

APPENDIX B

Table B1. Wedge clarity and online absorbance data for the 2013 direct clear juice (DCJ) trial.

May	CJ		DCJ		CCJ		FDJ_2	
	Wedge clar (WU)*	Online abs (AU)**	Wedge clar (WU)	Online abs (AU)	Wedge clar (WU)	Online abs (AU)	Wedge clar (WU)	Online abs (AU)
Number	3	8	3	9	-	17	1	34
Average	10	0.64	12	0.57	-	2.39	4	1.40
Min	8	0.40	9	0.36	-	1.99	4	0.05
Max	11	0.90	15	0.77	-	2.67	4	2.41
Std dev	1	0.17	2	0.12	-	0.22	0	0.53

June	CJ		DCJ		CCJ		FDJ_2	
	Wedge clar (WU)	Online abs (AU)	Wedge clar (WU)	Online abs (AU)	Wedge clar (WU)	Online abs (AU)	Wedge clar (WU)	Online abs (AU)
Number	8	10	25	44	-	19	-	5
Average	25	0.23	15	0.54	-	1.82	-	0.59
Min	17	0.03	12	0.09	-	0.79	-	0.47
Max	32	0.48	18	0.94	-	2.71	-	0.70
Std dev	6	0.14	2	0.22	-	0.67	-	0.08

August	CJ		DCJ		CCJ		FDJ_2	
	Wedge clar (WU)	Online abs (AU)	Wedge clar (WU)	Online abs (AU)	Wedge clar (WU)	Online abs (AU)	Wedge clar (WU)	Online abs (AU)
Number	46	6	12	37	-	3	18	19
Average	8	0.46	10	0.39	-	2.70	8	0.68
Min	2	0.18	8	0.20	-	2.60	4	0.40
Max	20	1.00	13	1.00	-	2.80	11	1.20
Std dev	4	0.27	1	0.15	-	0.08	2	0.19

November	CJ		DCJ		CCJ		FDJ_2	
	Wedge clar (WU)	Online abs (AU)	Wedge clar (WU)	Online abs (AU)	Wedge clar (WU)	Online abs (AU)	Wedge clar (WU)	Online abs (AU)
Number	16	15	74	74	11	11	-	-
Average	6	1.08	5	0.97	3	2.72	-	-
Min	3	0.64	2	0.47	2	2.21	-	-
Max	9	1.67	10	2.22	4	3.60	-	-
Std dev	2	0.28	1	0.35	1	0.39	-	-

* AU = absorbance units
** WU = wedge units

APPENDIX C
Screened bagacillo particle size analysis

Four particle size distribution tests were performed for bagacillo screened from DCJ. The bagacillo sample was placed in a set of vibrating screens of various sieve openings. After 10 minutes of sieving, the mass of bagacillo in each sieve was measured, and the results are shown in Table C1.

Table C1. Particle size distribution for bagacillo screened from direct clear juice (DCJ).

Sieve opening	**<106 µm**	**106-250 µm**	**250-500 µm**	**500-850 µm**	**850-1000 µm**	**>1000 µm**
Estimated avg size	53 µm	72 µm	375 µm	675 µm	925 µm	1250 µm
Sample 1 (% in range)	0.0%	1.0%	18.8%	12.5%	17.7%	50.0%
Sample 2 (% in range)	0.0%	0.1%	5.7%	8.7%	49.6%	36.0%
Sample 3 (% in range)	0.0%	4.3%	15.1%	11.3%	28.7%	40.5%
Sample 4 (% in range)	0.0%	5.4%	10.2%	29.1%	29.6%	25.7%
Avg (% in range)	**0.0%**	**2.7%**	**12.5%**	**15.4%**	**31.4%**	**38.0%**

The average bagacillo particle size was estimated to be 919 µm by summing the products of the average size, and weight fractions for each size range.

APPENDIX D
Calculation of percolation rates

To estimate percolation rate, a sight tube level gauge was fitted to the outside of the tray. The increase in juice level needed to be correlated with the increase in volume in the tray. Due to the non-uniform geometry of the tray, the relationship between level and volume was estimated through integration (performed by Professor Matthew Starzak at the SMRI), and verified by drawing the tray using a 3D modelling package (Google Sketchup). The relationship between level and volume in the tray is shown in Figure D1. The percolation was measured by stopping the pump on the outlet of the tray, and timing the increase of volume in the tray.

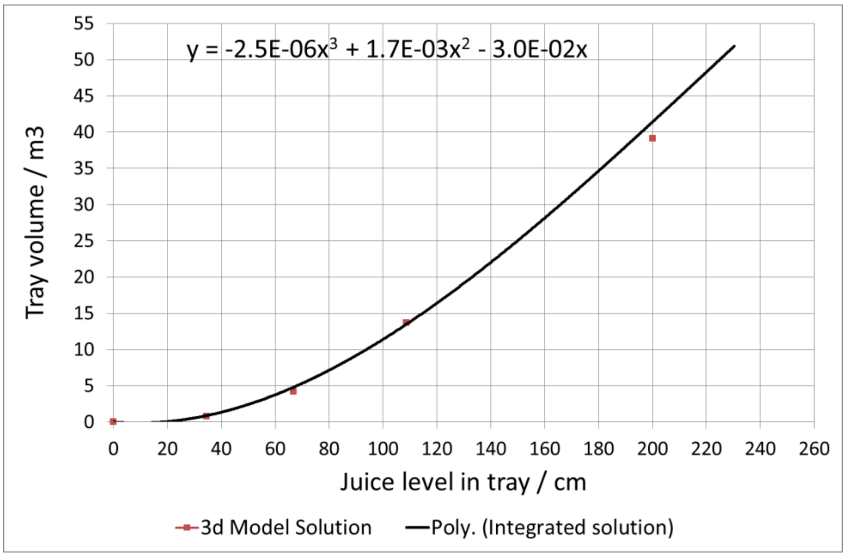

Figure D1. Relationship between juice level and tray volume in Maidstone diffuser trays.

The percentage recycle was then calculated using the method of Jensen (2013). The calculations are shown in Table D1.

Table D1. Percolation and recycle rate assumptions and calculations.

Date and time	23/08 (10:50)	23/08 (10:30)	27/08 (13:30)	23/08 (13:30)	03/09 (14:50)	03/09 (14:50)
Configuration	CCJ test 1	CCJ test 2	FDJ_2 test 1	DCJ test 1	DCJ test 2	DCJ test 3
Cane throughput (t/h)	170	170	170	170	178	193
Estimated fibre % cane	17	17	17	17	17	17
Fibre throughput (t/h)	29	29	29	29	30	33
Imbibition % fibre	307	307	307	307	217	320
Static juice holdup (kg/kg fibre)	3	3	3	3	3	3
Brix free water (kg/kg fibre)	0.25	0.25	0.25	0.25	0.25	0.25
Estimated fibre % bagasse	45	45	45	45	45	45
F_0 (m^3/h)	147	147	147	147	127	172
MPR ($m^3/m^2/min$)	0.15	0.15	0.15	0.15	0.15	0.15
Tray area (m^2)	36.0	36.0	36.0	36.0	36.0	36.0
F_{MPR} (m^3/h)	324	324	324	324	324	324
$F_{actual\ 1}$ (level increase)	169	189	209	246	268	264
PR ($m^3/m^2/min$)	0.08	0.09	0.10	0.11	0.12	0.12
$\mathbf{R_{required}}$	**55%**	**55%**	**55%**	**55%**	**61%**	**47%**
$\mathbf{R_{actual}}$	**13%**	**22%**	**29%**	**40%**	**53%**	**35%**

APPENDIX E
Calculation of lime consumption

Table E1. Calculation of the lime dosing rate to the diffuser at Maidstone under direct clear juice mode on 03/08/2013.

CJ pH	T'put (tch)	CaO conc (%)	Bredel SP 32 (L/stroke)
~7.3	180	11%	0.625

Pump	rpm	MOL rate (L/min)	Limed juice pH	Lime dosage (kg CaO/t cane)
Juice section P1	15	9.4	8.2	-
Juice section P2	18	11.3	8.8	-
Combined		20.6		**0.8**

Table E2. Calculation of the lime dosing rate to the diffuser at Maidstone under direct clear juice mode on 04/08/2013.

CJ pH	T'put (tch)	CaO conc (%)	Bredel SP 32 (L/stroke)
~6.5	190	11%	0.625

Pump	rpm	MOL rate (L/min)	Limed juice pH	Lime dosage (kg CaO/t cane)
Juice section P1	9	5.6	7.1	-
Juice section P2	12	7.5	7.9	-
Combined		13.1		**0.5**