PILOT PLANT PROCESSING OF CANE STALKS INTO SUGAR

By G. R. E. LIONNET and M. J. REID
Sugar Milling Research Institute, Durban

Abstract

The Sugar Milling Research Institute has developed pilot plant facilities to process cane stalks into A-sugar and A-molasses. The plant includes extraction, clarification, evaporation, pan boiling and centrifuging equipment. Design characteristics and operational procedures are discussed. This pilot plant facility has been used to process a number of cane samples and the results obtained with these samples are presented.

Introduction

A facility for carrying out the various unit operations on a pilot plant scale is an important tool for research. Apart from increasing the control of the operation, it also removes many of the interfering factors found on the industrial scale. On the negative side, it is not always certain that the results obtained apply to the industrial scale. Thorough comparative work can however be carried out to establish the validity of the results.

Over the last few years, the Sugar Milling Research Institute (SMRI) has developed pilot plant facilities to process cane stalks into A-sugar and A-molasses. The plant includes a small three-roller mill, a shredder and a press for the extraction stage; a clarification vessel, which acts as juice heater, liming vessel and clarifier; a two effect evaporator; a vacuum pan and finally a batch centrifugal. This facility requires 100-200 kg of cane stalks and will yield the usual intermediate products such as clear juice, mud and syrup, and finally 8-10 kg of A-sugar and A-molasses.

Extraction

Laboratory mill

The George Fletcher laboratory mill at the SMRI was acquired several decades ago to be used as a means of extracting juice from cane stalks for various purposes. It is a hand fed three-roll mill with rolls 300 mm wide and 200 mm in diameter. The roll shells are made of cast iron and have 4 mm pitch 60° grooves. A 4 kW motor drives the fixed top roll at 16 rpm which drives the two side rolls through pinions in the conventional manner. The nominal capacity of a mill of this size according to a catalogue is 900 kg per hour.

The two side rolls are maintained a constant distance from each other by draw bolts, but are free to float as a pair in relation to the top roll. Thus the discharge to feed setting ratio finds its own level depending on the hardness of the cane. The trash plate is also free to float horizontally and to a limited extent, vertically as well, being maintained in position only by the pressure of the cane which forces it downwards. The configuration would normally work very well provided the trash plate is not worn or damaged in any way.

The mill was modified about eight years ago to handle highly corrosive bagasse residue from acid hydrolysis. The discharge roll was removed and the top and feed rolls were machined down and hard-rubber lined. The mill was used in this form as a two-roll mill for a few years, but when it was required to mill cane again it had to be restored to its original configuration. New rolls were made, and an experimental trash plate made from high density polyethylene was installed.

When the mill was commissioned at the start of the cane deterioration project, the trash plate performed very well initially. However after a few hours of running there were several serious chokes, and the trash plate was replaced with the original badly worn mild steel trash plate. This did not solve the problem completely, and the mill was then fitted with a reversing switch so that chokes could be easily cleared. The new trash plate was found to have softened and distorted, which indicates that without adequate cooling a plastic trash plate will not survive in this environment.

Shredder

A size 10 Jeffco Cutter-Grinder is used as a shredder. This machine is of Australian manufacture, and is of a type used in that country for sample preparation. It has a vertical spindle fitted with a set of shear blades and hammers which cut and shred the cane in one operation. The preparation index of the shredded cane from this machine is usually above 95%.

Bagasse press

For final dewatering of the bagasse after milling, a Pinette Emidecau hydraulic press is used. This press is of the type used in Reunion for sampling purposes. It is fitted with a perforated pot into which a 150 mm diameter ram is pressed to squeeze the sample down to a moisture of about 45%. The maximum capacity of the press is 440 kN, but it is usually used at a level of 200 kN for one minute.

Operating procedures

Fifty kg of cane stalks are treated as one load and are fed manually through the mill. The juice flows through a coarse sieve and is collected in a 100 litre bin. The crushed stalks are added to 20 kg of imbibition water in a rectangular plastic container and mixed well. The imbibition water usually contains a bactericide.

The crushed stalks, after soaking in the imbibition water, are fed again through the mill. The bagasse is added to 15 kg of imbibition water, again containing a bactericide, while the juice is collected, as before.

After a third milling the final bagasse is collected in a plastic drum. The juice is added to the previous two portions.

The final bagasse is fed through the Jeffco cutter grinder, which produces a pulp. This pulp is then pressed at 200 kN for one minute, yielding the press juice, which is added to the juice from the mill. These procedures are summarised in Figure 1.

The combined juices are weighed, pasteurised (80°C) in a steam heated tank, and cooled to room temperature. The whole process takes 20-25 minutes. Samples are preserved with mercuric chloride and the bulk juice is frozen in 10 litre batches.

The press bagasse is mixed and sub-sampled. It is analysed for pol and moisture by the usual methods.

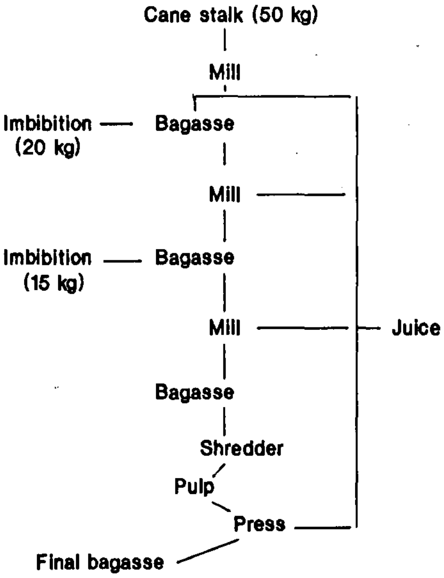

FIGURE 1 Summary of the extraction process.

The procedure is repeated to process all the cane. It is possible to treat four batches of 50 kg in a normal working day.

To date only nine sets of 200 kg each have been processed. Although improvements, particularly with respect to the time required, will be made, the results obtained are considered representative.

Pol extraction is calculated from the masses of pol in juice and in the final press bagasse. The average extraction was 92,6 (min. 91,7; max. 94,0). This was achieved with the high imbibition % fibre of 550. Pol % bagasse was 3,4 (min. 2,2; max. 4,4) and moisture % bagasse was 43,4 (min. 39,3; max. 45,6).

The extraction is obviously not as high as that obtained industrially. It might be possible to improve it by reducing the imbibition water during milling and using it at the pressing stage.

Clarification

Description

Clarification is by the usual defecation process. All the operations are done in a 150 litre tank, shown in Figure 2.

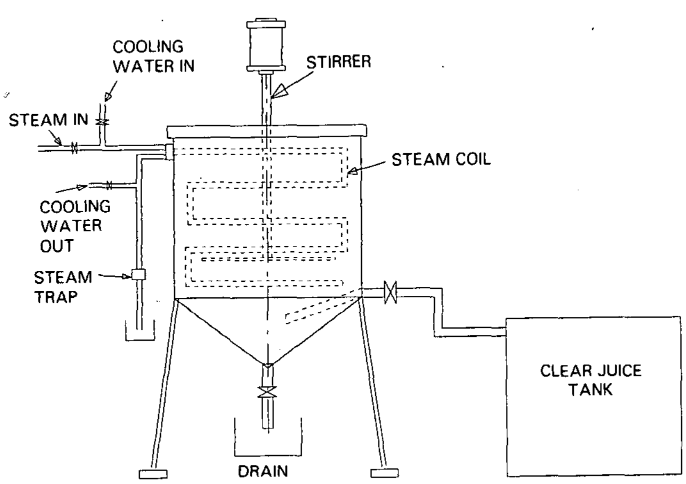

FIGURE 2 Schematic diagram of the clarification vessel.

The procedures for defecation are as follows. While stirring, the juice is heated to boiling point. At the boiling point, the steam flow is reduced to result in gentle boiling and milk of lime (10 g $Ca(OH)_2$/100 g) is added to bring the pH to 7,1-7,2. Gentle boiling is continued for about 2 minutes, to remove all the air. The steam is turned off and 5-10 ppm of flocculant are added. The stirrer is stopped and the mud is allowed to settle for a period of 30 minutes. Clear juice is sampled and then usually fed directly into the evaporator, through the holding tank. Mud is removed through the bottom valve, weighed and discarded.

The boiler which supplies steam for heating in the clarifier and pre-evaporator holding tank was installed in 1951. It is a Bastian and Allen electrode boiler rated at 70 kW at a pressure of 1 000 kPa. The electrode boiler is ideally suited to this type of operation as it is fully automatic and very safe. If it runs out of water, the current falls to zero and the boiler shuts down. The pressure control operates by varying the current and the load control merely changes the water level.

Results

There were problems with sample preservation for some of the tests at the beginning of this work. The purities measured in a second series of tests are shown in Table 1.

Table 1

Averaged purities, second series

	Mixed juice	Clear juice	Syrup	Massecuite
Pol/brix	83,3	83,3	83,1	82,9
Sucrose/brix	83,7	84,0	84,7	—

There is no clear evidence of an increase in purity over clarification. At this stage it can only be concluded that there are no signs of serious sucrose losses due to inversion and/or deterioration during the storing or processing of the juices and syrup. Deterioration could be a problem since it takes about four days to get to the massecuite stage and storage of material is inevitable.

The amount of lime used has been found to be inversely proportional to juice purity. This is shown in Table 2.

Table 2

Lime added as a function of juice purity

g CaO/kg brix in mixed juice	Juice purity (pol/brix)
2,3	94,4
3,2	90,6
3,5	88,4
3,7	81,5
3,9	74,5
4,9	64,6

Ash levels, reducing sugar levels and reducing sugar ash ratios are shown in Table 3. As noted earlier, there were deterioration problems during some of the runs. These abnormal results have not been included in Table 3. The results in this table show good agreement between clear juice and syrup. Ash increases by about 15% over clarification.

Table 3

Changes in ash and reducing sugars

	Mixed juice	Clear juice	Syrup	A-molasses
Ash % brix	2,1	2,4	2,4	5,2
Glucose % brix	2,7	2,7	2,5	5,0
Fructose % brix	2,9	2,8	2,8	5,8
Reducing sugar/ash ratio	2,0	1,7	1,7	1,6
Fructose/glucose ratio	0,94	1,0	1,0	1,1

Evaporation

Description

Towards the end of 1990 a two-effect evaporator designed to evaporate 12 litres per hour was built at the SMRI (Figure 3). The first effect consists of a 100 mm diameter stainless steel tube 600 mm long around which are wrapped three plate elements each of 1,25 kW, with a fourth element of 1,4 kW being arranged in a central tube fitted on the bottom flange. A glass cylinder 100 mm in diameter and 600 mm long is fitted above the 'calandria' and the vapour outlet is provided with a simple droplet eliminator. The juice inlet is arranged at the bottom of this vessel, and a small sight glass is provided near the top of the calandria just above the juice outlet. A level sensor is arranged to control a solenoid valve in the juice supply line. The vessel is fitted with a safety valve set at 30 kPa gauge.

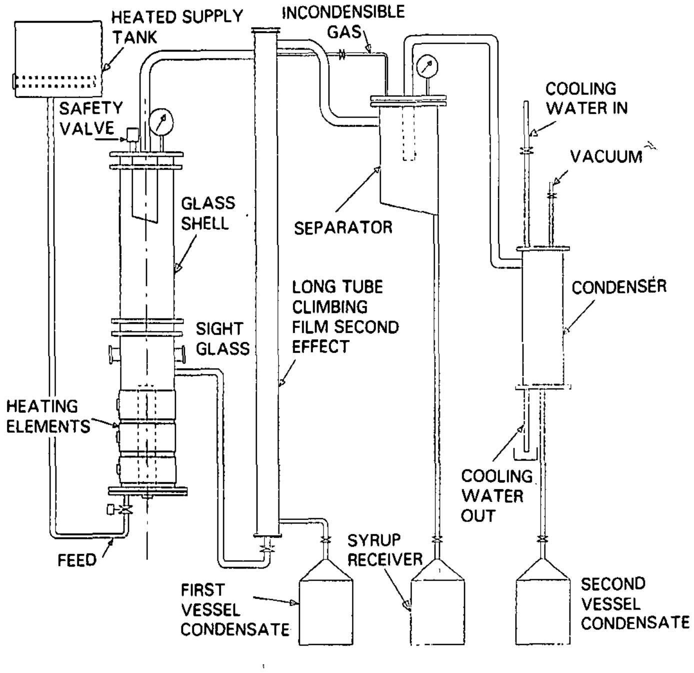

FIGURE 3 Schematic diagram of the evaporator.

The second effect has three stainless steel tubes 16 mm in diameter and 1 200 mm long, welded into tube plates which are fitted into a 50 mm diameter calandria using 'O' rings to facilitate quick replacement. The top of the vessel is provided with a sight glass and a mirror so that the boiling operation can be observed from ground level. The vapour and juice mixture from the top of the second vessel are separated in a small cyclone, the vapour being condensed in a water cooled heat exchanger. The condensates and the final syrup are collected in stainless steel vacuum vessels which have a capacity for a run of about four hours.

When the evaporator was commissioned, various difficulties had to be overcome. Some of the lessons learned were:

- The heat losses were higher than anticipated, being of the order of 1 kW even after the insulation was improved.
- The heat transfer coefficient of the second effect, which was designed to operate on the climbing film principle, was disappointing. Initial values of about 0,6 kW $m^{-2}{}^{\circ}K^{-1}$ were obtained.
- It is important to ensure steady state conditions. The condensate collection bottles were initially small and the process had to be interrupted to empty them. It took about 30 minutes for the evaporator to settle down again after this interruption. The new pots are larger, and they are now only emptied after each run.
- The 'house' vacuum system was used initially for incondensible gas removal. The variation in this vacuum was found to be excessive and a new, separate vacuum pump was eventually purchased for the evaporator. This solved the problem completely.
- The intermittent operation of the level control was another disturbance and hand feeding was eventually found to be preferable.
- The first vessel boils vigorously, causing excessive foaming and entrainment. The vessel was initially very short and had to be extended by the addition of a 600 mm long glass tube. The entrainment was much less, but the addition of anti-foam was still found to be necessary.

Two passes are required to produce a syrup of 60-65° brix. The first uses clear juice at about 11,5° brix and produces a syrup of about 30° brix, which is then used as feed for the second pass.

Crystallisation

Description

The SMRI pilot pan was used for all the boilings. This pan and its ancillary equipment have been described in detail by Bruijn (1964) and Lionnet (1987). The equipment is shown in Figure 4.

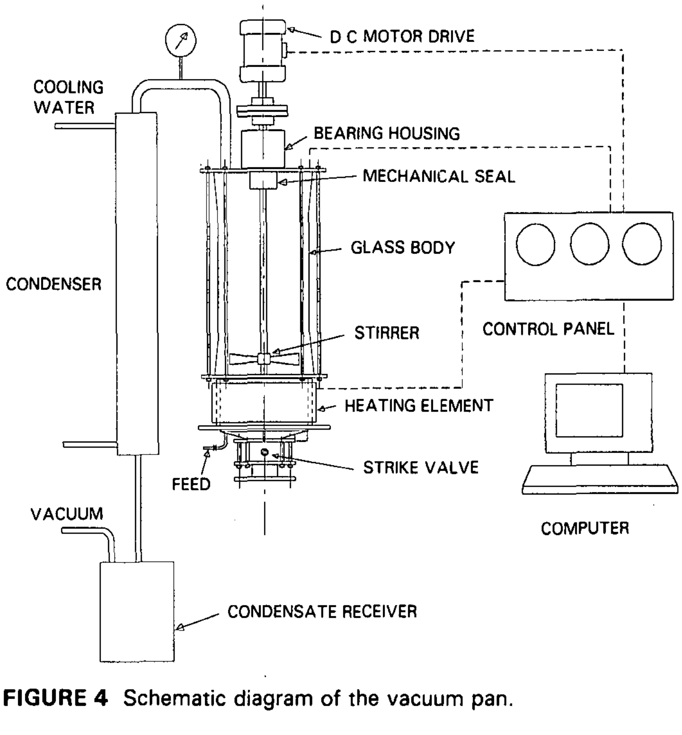

FIGURE 4 Schematic diagram of the vacuum pan.

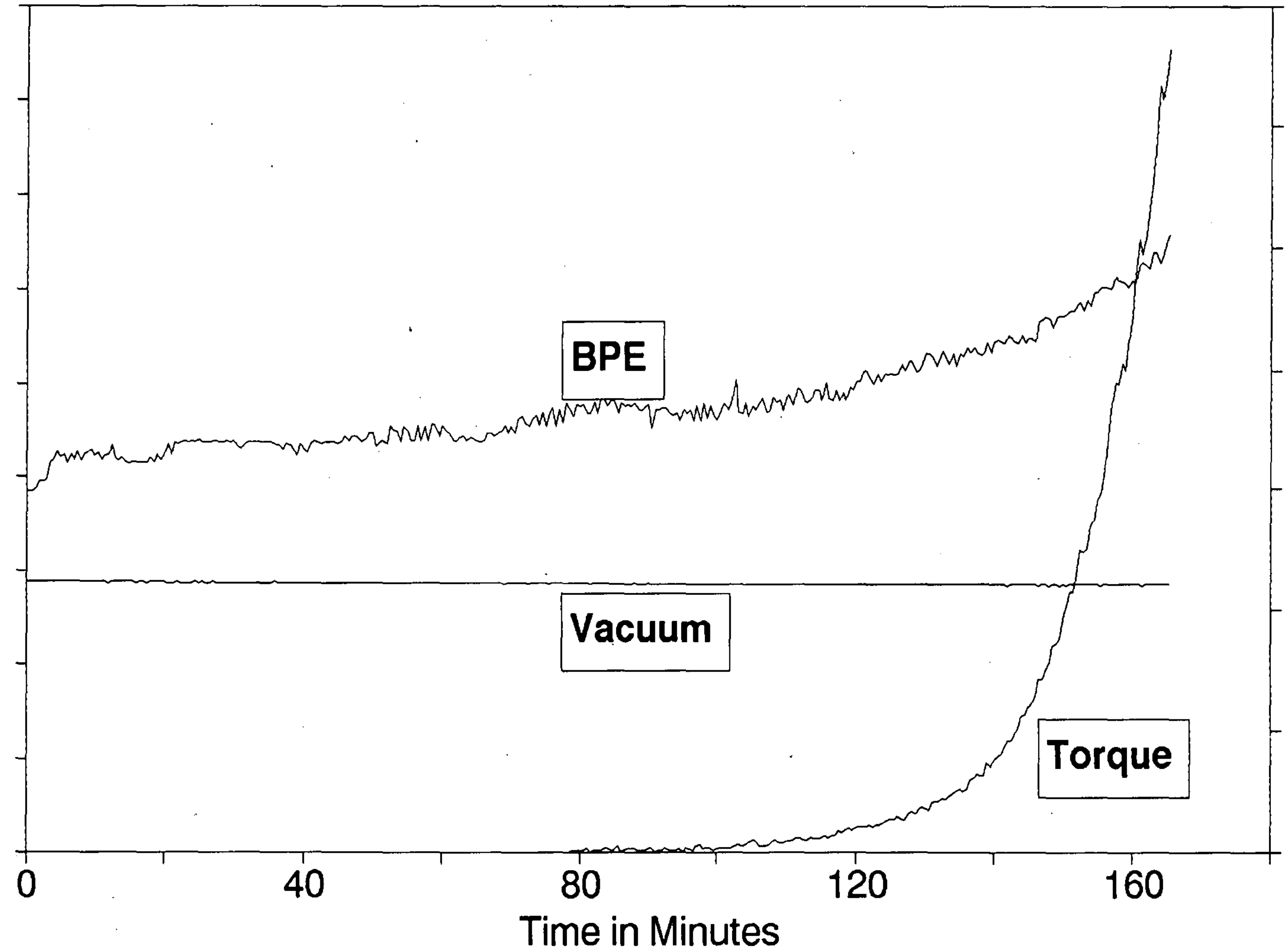

FIGURE 5 Boiling point elevation (BPE), vacuum and stirrer torque for a typical syrup boiling.

Table 4

Some pan-boiling results

Boiling time (h)	Massecuite brix	Exhaustion	Crystal content (%)	Crystal width (μm)	Crystal L/W ratio
2-3,5	92	65	50	340	1,4

Operating procedures

Syrup is concentrated and seed addition, using sieved fine crystals (mean width 140 μm), is based on the boiling point elevation, which for normal evaporator syrup is 7,5 to 8,0°C. At graining the pan contains about 7-8 kg of concentrated syrup which is about 30% of the final massecuite mass.

The syrup feed is heated to 60°C and feed control is manual, using a needle valve. The rate of feeding is based on conductivity and/or boiling point elevation, while the final brixing is based on the stirrer torque. All these parameters are displayed both as instantaneous values and as trends against time on the computer screen. They are also logged on a floppy disk. Typical values of boiling point elevation and stirrer torque are shown in Figure 5.

The syrup feed, condensate and seed are weighed. The mass of massecuite can thus be calculated. The massecuite is centrifuged, without cooling, in a Martin Christ laboratory centrifuge. The basket takes about 2 kg of massecuite per load. No wash water is added.

The sugar is mixed well with an equal weight of a saturated solution of refined sugar, and centrifuged again. The 'washed' sugar is allowed to air-dry and is then affinated by the ICUMSA method prior to analysis. Some data concerning the syrup boilings are given in Table 4.

A major difference between the pilot plant and industrial pans is the crystal size. It is possible to obtain bigger crystals, by using the massecuite as a footing for a second boiling. The crystal size achieved through one boiling is however consistent and this is adequate for comparative investigations on the pilot plant scale.

Table 5

Colour (ICUMSA), pH 7) throughout the pilot plant processing

DAC extract	Mixed juice	Clear juice	Syrup	Massecuite	Molasses	Affinated sugar
20 550	18 080	17 000	16 880	16 520	39 250	156

Table 6

Indicator values

DAC extract	Mixed juice	Clear juice	Syrup	Massecuite	Molasses	Affinated sugar
4,5	5,8	4,9	3,5	3,4	3,0	4,2

Table 7

Gums, expressed as ppm on brix, for the two series of deterioration tests

Deterioration		Mixed juice	Clear juice	Syrup	Molasses	Affinated sugar	% removed over clarification
Series	Day						
1	0	5 620	2 270	2 370	5 500	300	60
	7	5 390	3 560	3 540	7 420	270	34
	14	6 420	3 690	3 470	7 280	390	42
	21	7 260	5 190	5 250	12 690	—	28
	28	—	6 790	6 600	12 270	385	—
	35	12 880	9 170	9 460	16 250	535	29
2	7	6 830	3 440	3 390	7 960	—	50
	21	7 130	4 660	5 580	10 370	—	35
	28	9 000	6 120	7 200	15 760	—	32

Colour

Pilot plant operations allow colour to be compared. Average results are shown in Table 5.

These average values show a 12% drop from DAC to mixed juice, a result which is similar to that found for milling tandems in industry. There is a 6% drop over clarification but clear juice, syrup and the A-massecuite show similar colours.

The affinated A-crystal colour is much lower than that of commercial VHP sugar, which ranges from 600 to 800 units. There are a number of reasons for this. Firstly, the syrups used here are much lower in colour than industrial A-pan feed, which can show colours between 25 000 and 30 000 units. Secondly, it has been shown (Lionnet 1988) that colour transfer can increase by about 20% for every 100 μm of crystal width, and finally, the seed here consists of refined sugar crystals of low colour as opposed to the B-crystals generally used industrially.

Indicator values (IV), i.e. the ratio of colour at pH 9 to the colour at pH 4, are shown in Table 6. The IV tends to be lower in syrup, massecuite and molasses.

Gums

The two series of samples processed to date were involved with cane deterioration. Gums were found to increase as the cane deteriorated, but 30-60% of the gums were removed over clarification. Individual results are shown in Table 7.

There is no doubt that gums increase as deterioration proceeds. The usual defecation process appears to remove between 2 000 and 3 500 ppm of gums on brix, independently of the amount in mixed juice. The percent removed thus decreases as the level increases in mixed juice. There is little change between clear juice and syrup. The level of gums in the crystal appears to increase, as the concentration in syrup increases. The large increases of gums in syrup and A-molasses would be expected to cause viscosity related problems during processing.

Conclusions

The pilot plants developed at the SMRI are now fully functional and have been used repeatedly to produce A-sugar and A-molasses from cane stalks. The plants can be used to investigate specific operations. The evaporator for example could be used to study heat transfer coefficients or scale problems, an approach which has recently been documented by workers at the Audubon Sugar Institute. It can also be used to study effects due to cane quality. The results given in this paper concern cane deterioration but other aspects, such as the effects of extraneous matter, could be investigated. Finally, another area which could be examined would be the use of chemicals, for example to control colour or viscosity.

Acknowledgements

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