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PRELIMINARY EXPERIENCES WITH A FALLING-FILM EVAPORATOR PILOT PLANT

By [1]J. R. FITZGERALD, [2]D. H. SEILLIER and [3]J. S. SITHOLE

[1]*CG Smith Sugar Limited, Technical Services*
[2]*CG Smith Sugar Limited, Technical Services now Genref, Durban*
[3]*CG Smith Sugar Limited, Illovo*

Abstract

The performance of a falling-film evaporator trial plant during the first year after installation at the CG Smith Sugar Illovo mill is described. Operating under conditions similar to those experienced in the mill's raw house first effect evaporator, the unit confirmed most of the reported characteristics of this type of plant and proved easy to operate. Problems experienced were associated mostly with ancillary and support equipment. The rate of scaling was found to be much less than expected.

Introduction

The application of Process Integration or 'Pinch Technology' principles to the cane sugar industry has demonstrated immense potential for energy savings within the CG Smith Sugar Group's sugar factories (Seillier and Brouckaert, 1988, Seillier, 1991). Depending on the level of integration introduced, this could vary from the complete elimination of any supplementary coal burning (if practised), to the release of large quantities of bagasse fibre or energy for by-product use.

Energy savings are dependent on the adoption of higher temperatures and smaller approaches in the raw house evaporator. These conditions would be conducive to high inversion losses if practised in the evaporator vessel designs currently in use within the South African sugar industry. Falling-film evaporators, however, offer a solution to most of the problems in this regard.

Falling-film evaporators have extensive application within industries handling heat sensitive materials such as corn syrup, fructose and glucose, and recently in the sugar refining and beet sugar industries. Their use within the cane sugar industry has, however, been hampered because they are temperamental, difficult to operate, prone to scaling and the distributor has a tendency to block. The authors are aware of two installations only in the industry world wide, both being in combination with existing or conventional sugar evaporators (Bhargava *et al.*, 1989).

Many publications, both technical (Tobe, 1987) and commercial (GEA Wiegand, 1988), in which the principles and characteristics of falling-film evaporators are discussed, are available. These will be briefly reviewed.

Falling-film reportedly offers the following advantages over conventional designs now used in the industry:

- shorter residence times
- higher heat transfer coefficients (notably at high brix values)
- smaller approach temperatures
- flexibility in capacity
- smaller floor area requirement

Disadvantages stem mainly from a reliance on chemical cleaning, and the need to maintain a fully wet surface or a minimum liquid flow at all times.

Objectives of the trials

Objectives of the falling-film evaporator pilot plant trials are:

- To confirm the suitability of falling-film evaporation as an operating unit in the South African cane sugar milling environment
- To determine the operational and design characteristics of falling-film evaporators run under existing and proposed operating conditions
- To determine the effect of falling-film evaporation at existing and elevated temperature profiles on the physical and chemical properties of juice and syrup.

Description of the pilot plant

The design chosen for the pilot plant was a vertical tube calandria with an independent laterally adjacent centrifugal or cyclonic separator. The components of this type of vessel are shown in Figure 1. The design offers a lower juice retention over designs with internal separators and vapour ducts.

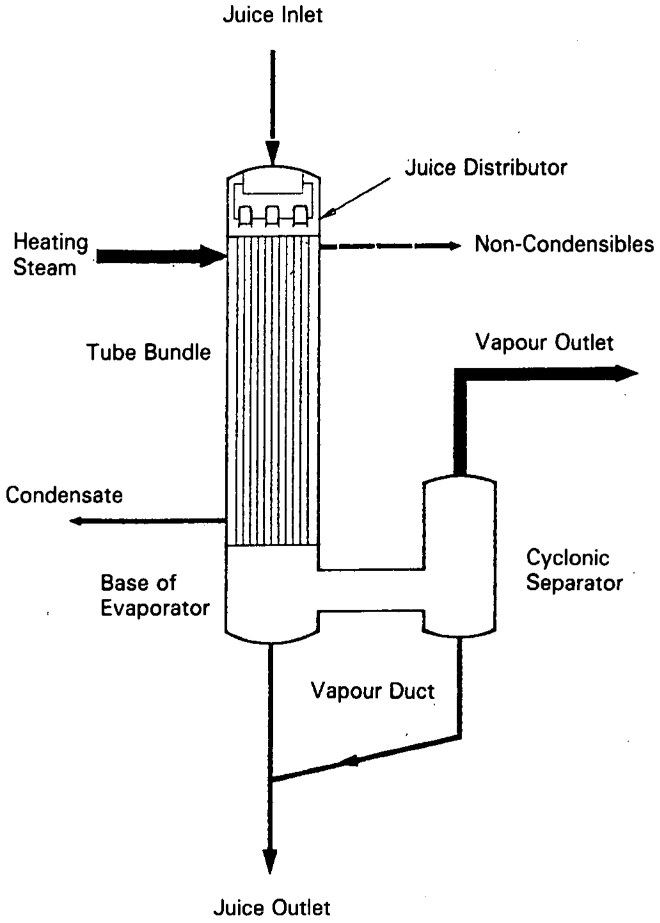


FIGURE 1 Falling-film evaporator with independent separator.

As the presence of suspended solids in clear juice would block the holes in a simple perforated plate-type distributor, a free-flow design based on tubular weirs and teeth was chosen. The operating principle of the distributor plate installed is shown in Figure 2.

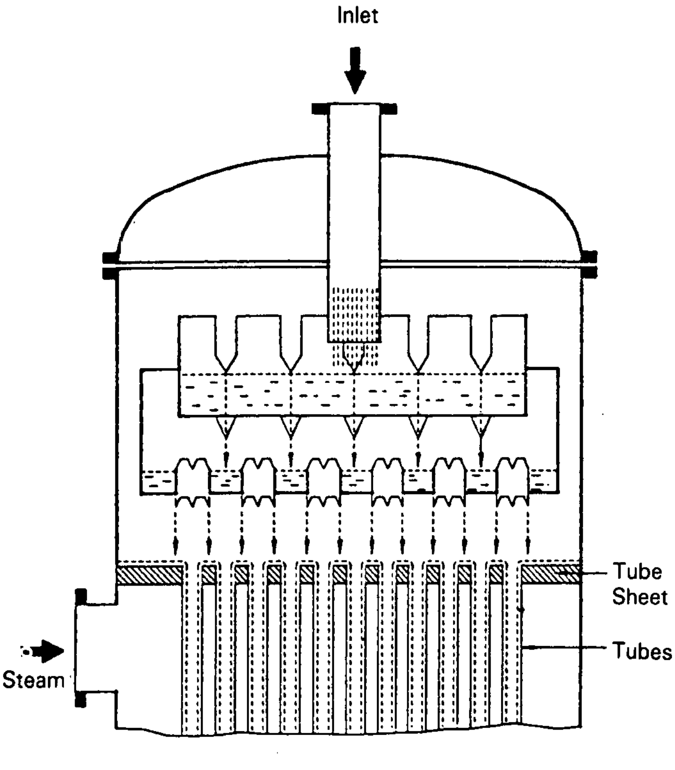


FIGURE 2 Juice distributor.

Full specifications for the pilot plant evaporator are listed in Table 1, and a simplified flow and instrumentation diagram of the installation is shown in Figure 3. Apart from the additional monitoring instruments, the plant was intentionally fitted and operated with the same controls that would have been proposed for a full-scale commercial unit. A small free-flow plate heater of 3,68 m^2 was installed to pre-heat the feed and the chemical cleaning solutions when required.

Table 1

Evaporator trial plant specifications

EVAPORATOR		
Type:	Vertical tube falling-film	
Distributor:	Tubular weirs	
Tubes:	Material of construction:	304L SS
	Number of tubes:	22
	Outside diameter	50,80 mm
	Inside diameter	48,40 mm
	tube length	10,00 m
	Effective tube length	9,98 m
Shell:	Overall height (incl. base)	15,50 m
	Inside diameter	386
VAPOUR SEPARATOR		
TYPE:	Independent cyclonic vapour separator	
	Inside diameter	0,76 m
DESIGN PARAMETERS		
Heat transfer area:		
	Based on tube O.D.	35,04 m^2
	Based on tube I.D.	33,38 m^2
Wetting rate parameters		
	Total wetted perimeter	13,35 m
	Minimum wetting rate - ref. Wiegand	12,00 ℓ/h/cm
	Minimum flow per tube	182,46ℓ/h
	Minimum flowrate ex Vessel	4,01m^3/h

Operational observations

Delayed and protracted commissioning, problems with ancillary equipment and a relatively short season limited the work that could be undertaken during the season. It was decided, for ease of operation in the first run, to operate on a once-through basis despite the fact that it would not be able to achieve the same duty as in the factory's first effect evaporator without recycle. This is because the installed tube is 10 metres long. It should be noted, however, that the objective was to specify a plant with the least amount of necessary recycling.

Problems experienced with the trial plant were mainly related to the pumps, incorrect seals, and control instrumentation. As there was no available standby pump, the need to use the recycle pump as a replacement precluded the use of recycle for most of the season.

On line and operating on a 24-hour basis, the unit proved stable, reliable, and easy to control with minimum operator attention. In less than 15 minutes sufficient automation was available to achieve the desired operating conditions and these were easily maintained. The cyclonic separator performed well; spot tests on samples of the condensed vapour yielded less than 10 ppm sucrose.

The unit was chemically cleaned by circulating a preheated 90°C sodium hydroxide solution for about four hours, followed by flushing with water. For the first run, a solution strength of 20% m/m was used but this was dropped to 10% m/m for the later runs with no loss of effectiveness. An inspection of the tubes prior to cleaning in each case revealed only a very thin black film which could be removed easily by wiping with a finger tip. After cleaning, the tubes were 'shiny' and bright. No blockage was seen in the distributor.

Operational parameters

Heat transfer coefficients

For design purposes the overall heat transfer coefficient (OHTC) is required. The overall temperature difference and the heat transferred can be measured directly. Based on the relationship $q = - UA(dT)_{lm}$, the OHTC 'U' for the known area may be calculated. As the main resistance to heat transfer (scale) is time dependent, it is necessary to determine the coefficient as a function of time. Plotting OHTC against time will give the rate of fouling, and its value after chemical cleaning will determine the effectiveness of the cleaning method used.

Figures 4 and 5 plot the OHTC against days on line. In most instances, the coefficients represent the average of six determinations over the 24 hour period. Whether based on juice flows or brix recordings across the unit, an average of 3,0 kW/m^2/°C was consistently being recorded after the first few days of operation in both runs. This result was confirmed in the third run, the results of which are not shown. This value is approximately 15% higher than the in-house design figure used for Kestner or climbing-film evaporators, and confirms the figures reported in the literature. All runs were conducted under similar operating conditions.

Wetting rates

Wetting rate is a measure of the amount of liquid flowing down the tubes in the vessel and is used to ensure that no part of the heating surface is allowed to run dry. Wetting rates are quoted in terms of flow from the vessel divided by the total wet perimeter, i.e. vol/unit time/total tube circumference. For a fixed area, the required wetting rate can be

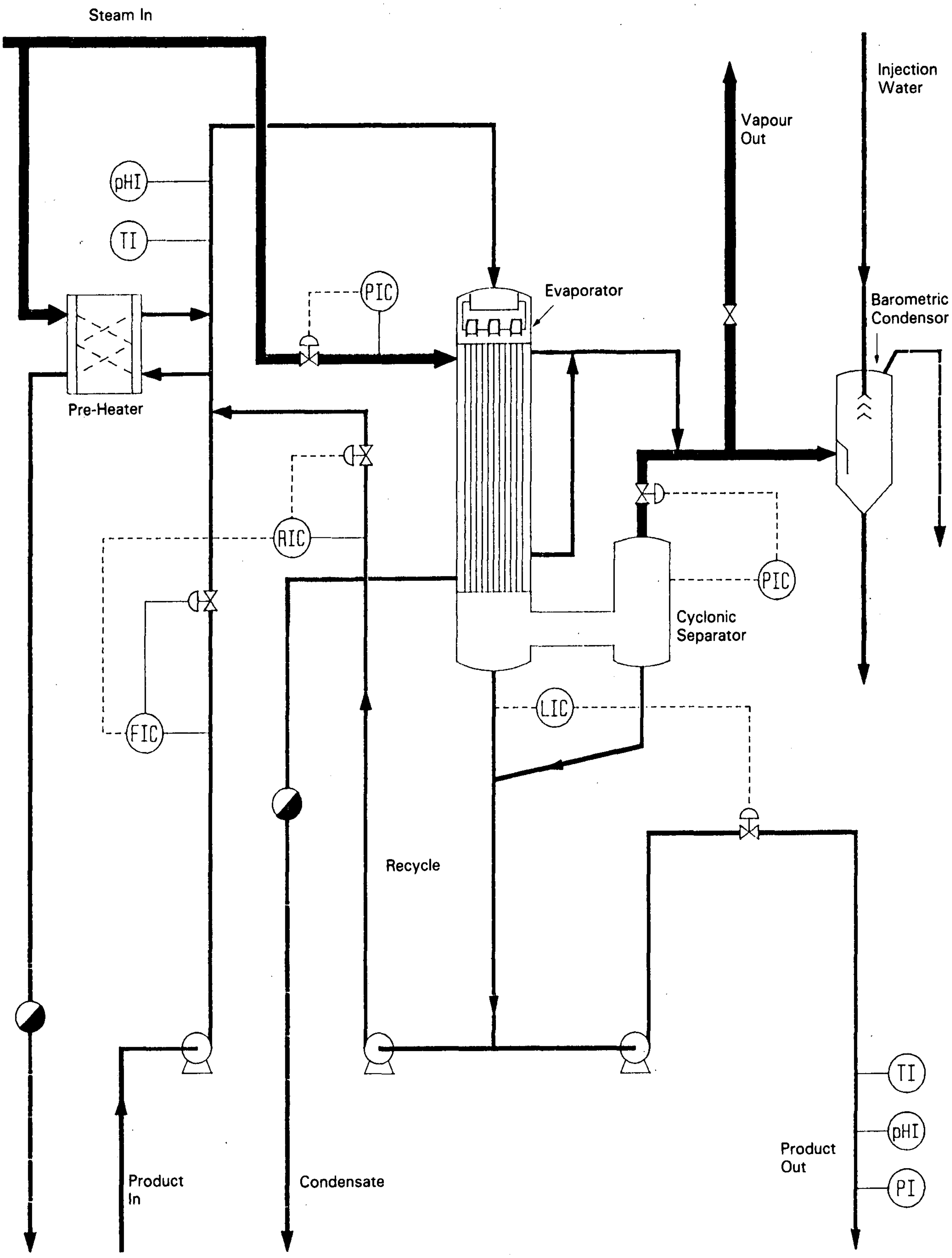
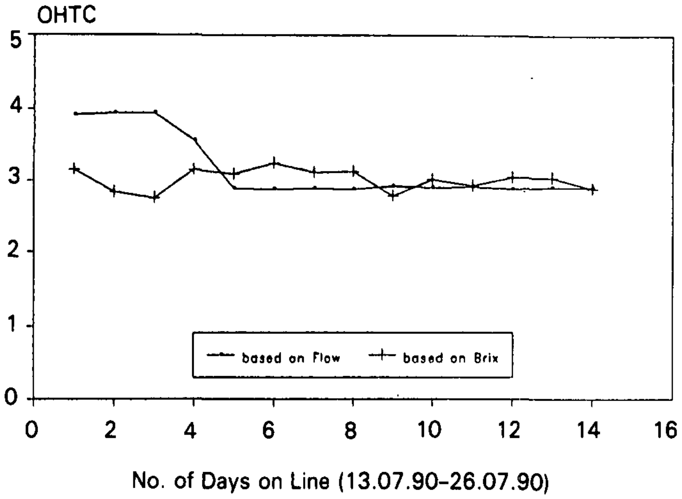
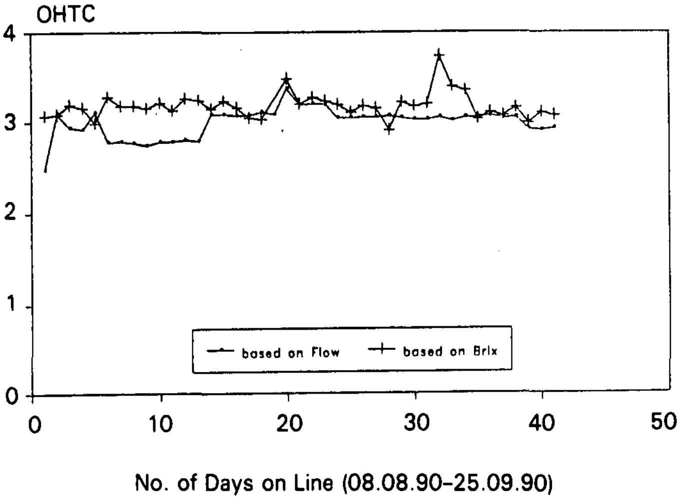


FIGURE 3 Flow and instrumentation diagram of trial plant.



OPERATING CONDITIONS
Exhaust: 196.0 kPa Vapour: 141.5 kPa
Juice Flowrate In: 7.1 cu.m/hr

FIGURE 4 Overall heat transfer coefficient (OHTC) vs time - Run 1.



OPERATING CONDITIONS:
Exhaust: 182.0 kPa Vapour: 140.5 kPa
Juice Flowrate IN: 7.1 cu.m/hr

FIGURE 5 Overall heat transfer coefficient (OHTC) vs time - Run 2.

maintained either by changing the liquid flow to the evaporator or by increasing the recycle around the evaporator for a reduced input feed rate, the operating criteria used being dependent on the duty required.

The limited results obtained to date (Table 2) support the claim that falling-film evaporators exhibit good turn-down characteristics by maintaining evaporation performance over the range of loadings monitored. The OHTC is normally expected to show a rapid decrease in value at and below the minimum wetting rate, but this aspect was not investigated.

For these trials, a minimum liquid wetting rate of 12,0 l/hr/cm, as proposed by GEA Wiegand (1988), was assumed and for most runs the plant was operated at around 1,5 times this value.

Table 2

Effect of wetting rate on heat transfer coefficient

Mass flow rate - OUT tons/hour	Wetting rate ℓ/h/cm	OHTC (based on flow)	OHTC (based on brix)
4,2	12,56	3,17	3,01
4,5	13,45	n/a	3,56
5,2	15,55	2,85	3,02
5,8	17,34	3,04	3,17
6,0	17,94	3,11	3,20

Operating conditions:

Exhaust pressure:	196,00 kPa
Vapour pressure:	141,50 kPa
Inlet conc:	11,00° brix

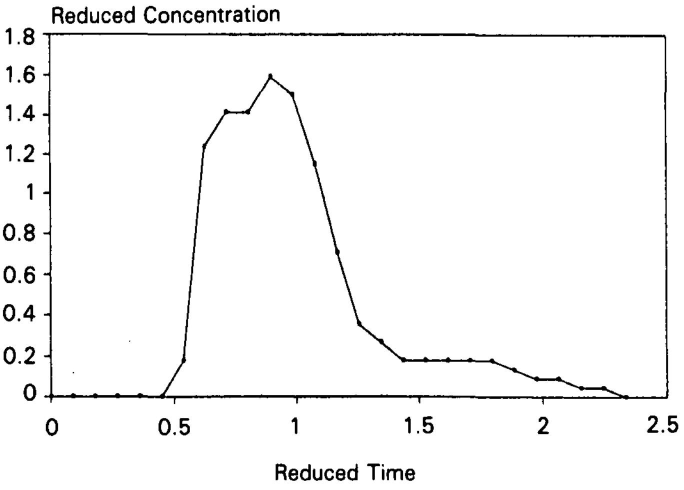
Residence time distributions

Residence time distribution tests were conducted using sodium chloride as a tracer and continuous in-line conductivity recordings to confirm the predicted short retention time. Table 3 lists the average retention times obtained for a limited range of flow rates without recycle, while a typical residence time distribution is shown in Figure 6.

Table 3

Effect on flowrate on mean residence time

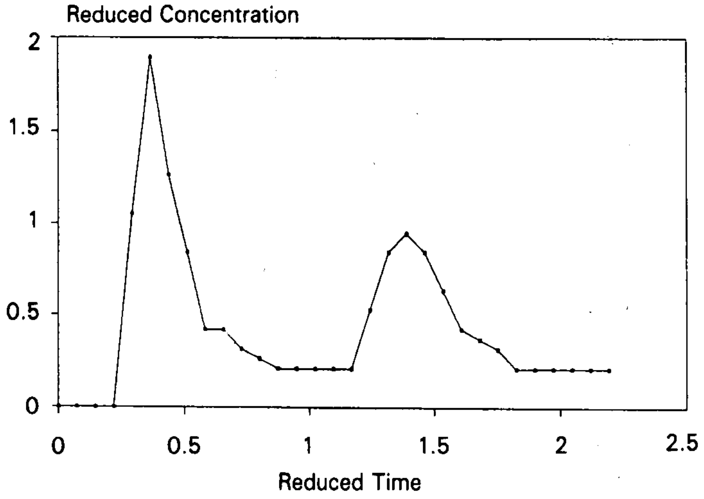
Mass flow rate - IN tons/hour	Mean residence time seconds
5,00	36,50
6,00	32,97
7,00	27,90



Flow Rate - cu.m/hr: 7,0
Mean Residence Time - secs: 27,9

FIGURE 6 Residence time distribution without recycle.

These results confirm both the plug flow characteristic of the plant as well as the predicted retention times based on film thickness correlations, the reduction in retention time being due mainly to the finite volumes associated with the distributor and the sump. As confirmation, Figure 7 shows the residence time distribution for 120% recycle on an inlet flow of 5 m^3/hr, with the plug flow characteristic dominant even in the second pass through the tubes.



Total Flowrate - cu.m/hr: 11,0
Recycle: 120% on Feedrate

FIGURE 7 Residence time distribution with recycle.

Sucrose inversion and colour formation

The effect of the exposure of impure sucrose solutions to high operating temperatures was an important aspect of the investigation. This is shown in Table 4, where the theoretical inversion levels (as predicted by Vukov's equation) in a falling-film vessel are compared with conventional vessel designs of the same heating surface and operating under the same first effect duty.

A series of catch samples were analysed by the SMRI for product deterioration across either the factory's Kestner vessel or the trial plant at existing conditions. Parameters measured included fructose, glucose, sucrose and colour. The results proved inconclusive and at best demonstrated the vagaries of catch sampling. Due to the relatively small changes at short retention times and conditions, it is doubtful whether composite sampling would have led to an improvement in accuracy at this stage of the investigation.

Anticipating this problem, however, continuous on-line pH monitoring of both the feed and the product had been installed on the trial unit, and regular comparisons were made with the factory's first effect vessel. Laboratory measurements (at 21°C) indicated a pH drop across the Kestner vessel of about 0,35 units (standard deviation: 0,13) and 0,07 units (standard deviation: 0,03) across the trial plant. A similar decrease was confirmed using the continuous on-line measurements of pH at operating temperatures on the trial plant.

Conclusions

Although the conditions under which the trial plant operated during the first year did not quite match those of the factory's first effect evaporator, it is believed that this type of plant is suitable for use within the CG Smith Group's cane milling operations. Problems experienced with the pumps and instrumentation on the trial unit demonstrated the dependence of this type of unit on these items for maintaining a wetted surface at all times when steam is being fed to the calandria.

The trial unit confirmed most of the reported characteristics of this type of evaporator, and exhibited a scaling rate which was much lower than that of conventional evaporators for a similar duty. The scale was easily removed by chemical cleaning with sodium hydroxide solutions.

Acknowledgements

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Table 4

Theoretical inversion losses for different evaporator designs

Vessel type:	**FALLING-FILM GEA Wiegand**	**CLIMBING-FILM (Kestner)**	**SHORT TUBE (Roberts)**
Heating surface - m²	3000,0	3000,0	3000,0
Tube dimensions:			
Nom. Tube Length - m	15,0	7,0	2,5
Tube diameter (OD) - mm	50,0	50,0	50,0
Tube pitch - mm	48,4	48,4	48,4
Shell diameter (ID) - m	2,586	3,786	6,449
Liquid flowrate IN - tons/hr	250,0	250,0	250,0
Concentration IN - °Brix	11,0	11,0	11,0
Concentration OUT - °Brix	16,6	16,6	16,6
Vessel temperature - °C	114,0	114,0	114,0
SPACE TIME - min	0,548	4,962	15,884
INVERSION - %	0,0126	0,1138	0,3637