# PRELIMINARY ASSESSMENT OF A RISING FILM PLATE EVAPORATOR

[1]DC WALTHEW, [1]A WIENESE, [2]R SQUIRES AND [3]C FRIEDRICH

[1]*Sugar Milling Research Institute, University of Natal, King George V Avenue, Durban, 4001*
[2]*Glendale Sugar Ltd, PO Glenmill, 4452*
[3]*Technische Universität, Berlin, Germany*

## Abstract

A rising film plate evaporator was installed as a second effect at Glendale mill during the 1995 season. The effect on the overall steam balance is considered. Although the season was short some heat transfer measurements were possible, and these gave encouraging results. Aspects of fouling and cleaning, including scale analysis, are discussed.

*Keywords:* Plate evaporator, fouling, scale, Glendale

## Introduction

The Glendale (GD) sugar factory wants to increase its cane throughput from 82 to 95 t/h while at the same time improving the steam efficiency. To meet both these requirements some changes were made of which an increase in evaporator capacity was the main one. It was decided to expand the second effect by installing a plate evaporator (PE) in parallel with an existing Roberts vessel. The choice of a plate evaporator instead of a conventional Roberts vessel was based on the following:

- The plate evaporator is claimed to have significantly higher heat transfer coefficient (HTC) values. Because of this a smaller heating surface is required which reduces the evaporator size and mass.
- In a plate evaporator the plates are designed to promote turbulence which should reduce the fouling rate. Cleaning of the plate evaporator is the greatest concern.
- A plate evaporator is more flexible in that the surface area can easily be increased or reduced by the addition or removal of plates.

This paper is a preliminary assessment of the GD plate evaporator (Alfa Laval EC500 PE). Although the factory operated for only a short period during the 1995 season, some HTC values were measured. They are compared with typical HTC values from Roberts and Kestner evaporators in the industry. However, the major unknown regarding the local installation of a PE is its susceptibility to fouling, and the ease with which it can be cleaned in place without the need for dismantling. Therefore observations made in this regard as well as findings regarding the scale composition have been considered.

The PE operated for a total of 400 hours. The evaporator was cleaned twice, in place (without dismantling) with sodium hydroxide, firstly after about 370 hours of operation and

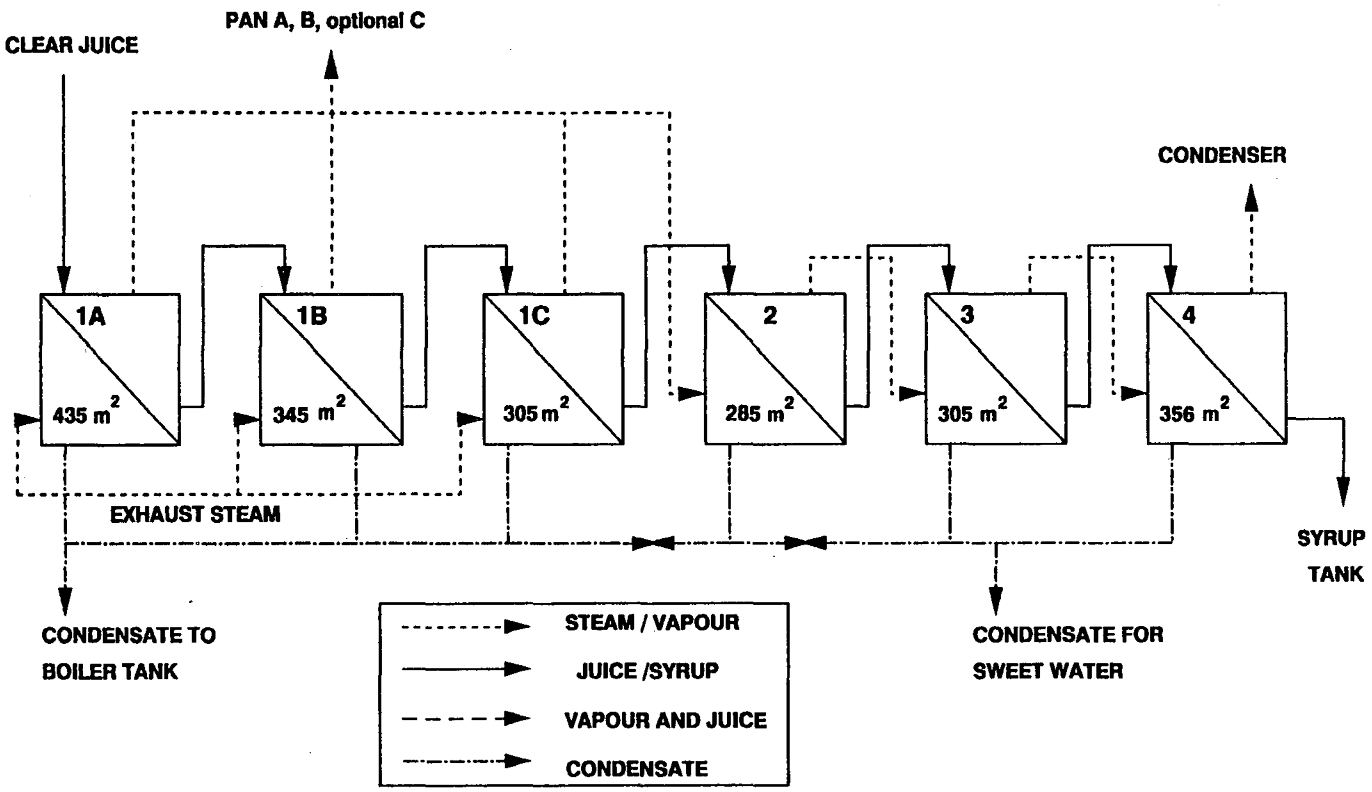


**FIGURE 1:** Evaporator station configuration at GD before installation of the PE.

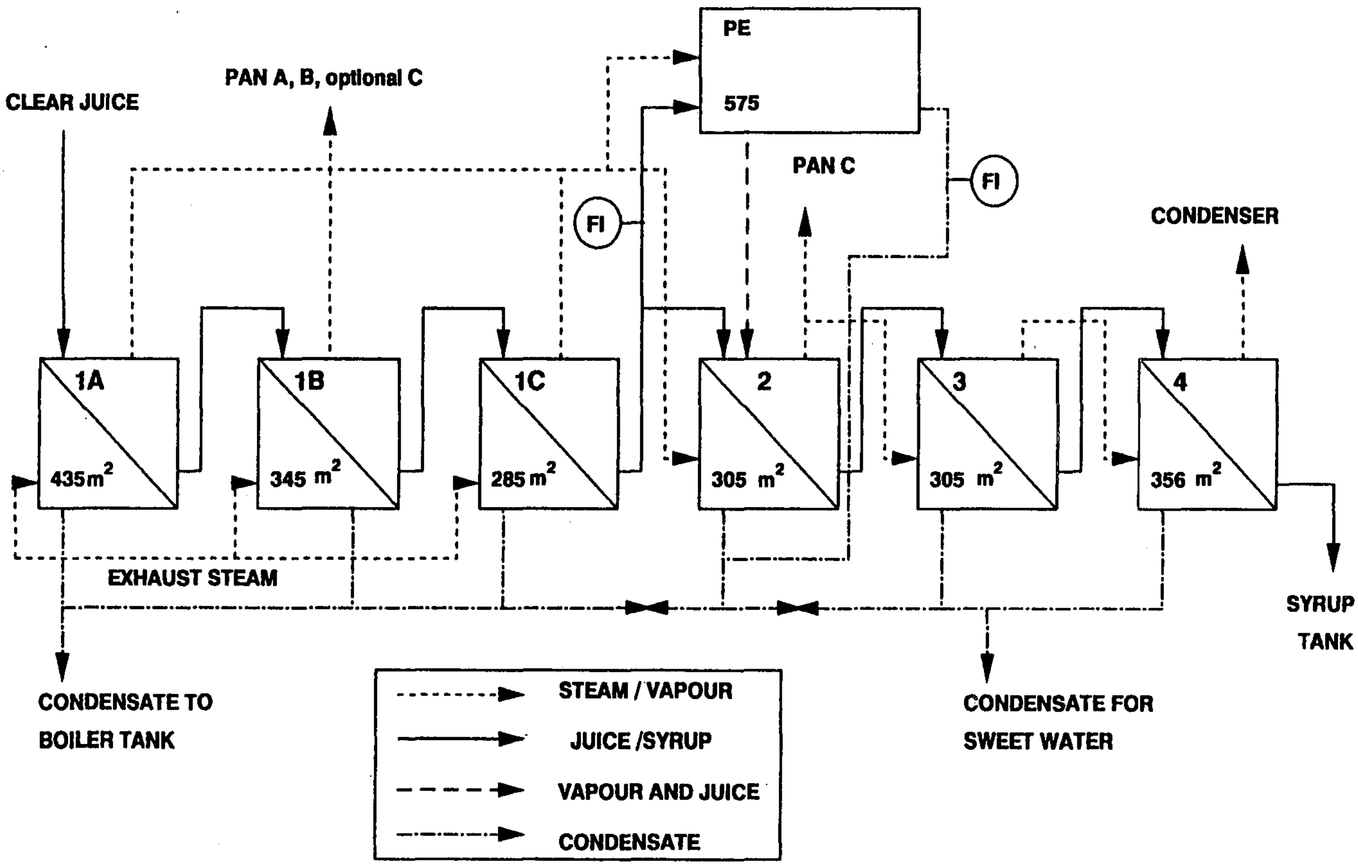


**FIGURE 2:** Evaporator station configuration at GD after installation of the PE.

again at the end of the period. At the end of the season the PE was dismantled to examine the plates regarding the effects of fouling and cleaning.

### Description of the installation

Prior to the expansion, all evaporator vessels were of the Roberts type, with three units making up the first effect, and one vessel each in the remaining effects, as shown in Figure 1. Installation of the PE involved a reconfiguration such that the vessel previously used as a second effect now became part of the first effect and the 1c vessel could operate in parallel with the PE as shown in Figure 2.

Table 1

Alfa Laval plate evaporator data

| | |
|---|---|
| Surface area | 574,5 m² |
| Surface area of one cassette | 2,61 m² |
| Plate thickness | 0,6 mm |
| Plate gap minimum | 10 mm |
| Plate material | Stainless steel 316 AISI |
| Gasket material | EPDM |

The juice flow to the PE was controlled manually in such a way that any drop in the juice flowrate out of the first effect would result in the amount of juice flow to the Roberts vessel being reduced in favour of maintaining the flow to the PE. This was done to ensure that the PE operated at the flowrates specified by the manufacturer. The two phase outflow of the PE (vapour and juice) was directed to the second effect Roberts vessel, which acted as a separator. The Roberts vessel was modified by cutting into the downcomer located on the side of the vessel.

The climbing film plate evaporator itself has been described in some detail by Nilsson (1994) and a drawing of the EC500 is shown in Figure 3. Table 1 is a summary of the unit's specifications.

### Energy considerations

The 1991-92 season was the last normal year before the drought. In that season the average crushing rate for GD was 82 t/h with a high pressure steam usage of 56 t/h. The fuel to

Table 2

Effect of evaporator changes on the steam balance

| Parameter | 1991-92 Season | 1995-96 Season |
|---|---|---|
| Cane throughput (t/h) | 82,07 | 95,00 |
| Area*HTC (kW/°C) | 518,70 | 2393,60 |
| V1 bleed (t/h) | 36,92 | 39,93 |
| V2 bleed (t/h) | 0,00 | 5,12 |
| Syrup brix (%) | 58,33 | 68,00 |
| V1 pressure (kPa(a)) | 125,00 | 128,00 |
| HP steam (t/h) | 55,93 | 59,66 |
| Exhaust steam (t/h) | 59,92 | 63,27 |
| Let down steam (t/h) | 11,12 | 6,11 |
| Bagasse to boilers (t/h) | 25,29 | 29,28 |
| Coal to boilers (t/h) | 1,14 | 0,64 |

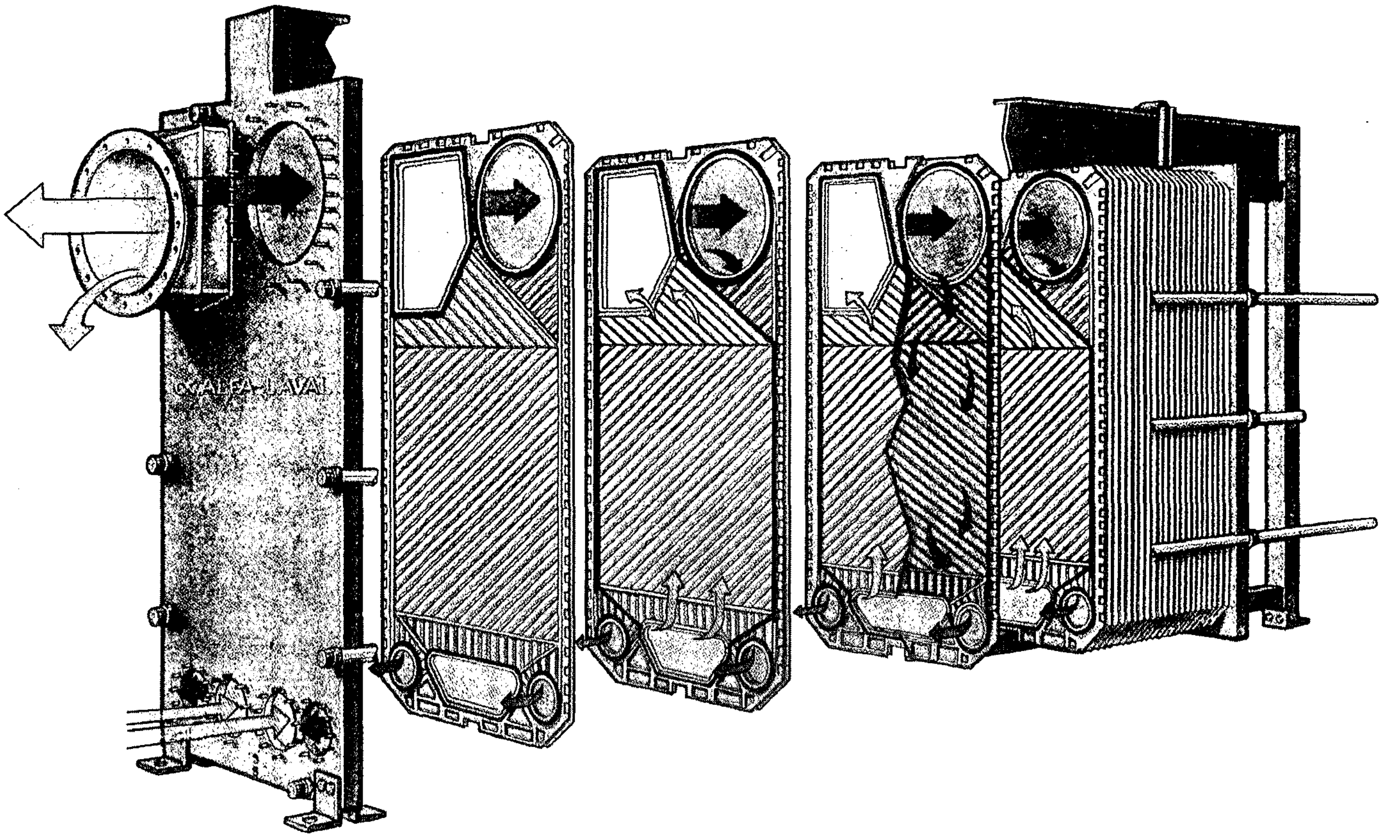


**FIGURE 3:** The EC500 plate evaporator (with permission of Alfa Lavel (Pty) Ltd).

produce that steam was in the form of bagasse and coal. The coal consumption was of the order of 14 tons per 1 000 tons of cane. To cater for an increase in cane throughput to 95 t/h and an improvement in steam efficiency, changes were made to the configuration and operation of the evaporator station. These changes were an expansion of the second effect, an increase in exhaust pressure and an increase in vapour bleeds. Each of these changes results in an increase in syrup brix. This shifts the load from the pans to the evaporators and is more steam efficient. The increase in exhaust pressure has the added advantage that it raises all vapour pressures which favours the use of vapour bleeds. It has not been possible to confirm these effects in practise due to a very short and abnormal season. Some of the expected results, however, are given in Table 2.

In relation to the cane throughput the coal consumption dropped from 14 to 7 tons of coal per 1 000 tons of cane. The fall in let down steam showed itself last season in the more regular blow off of steam and needs to be watched in the coming season.

## Experimental

*Calculation of the HTC*

The performance of the PE was monitored by calculating the HTC from juice flowrate and brix measurements and by measurement of condensate flowrates. No significant difference between the two methods was found. For simplicity, therefore, only the juice flowrate and brix method will be considered in this paper and is designated the apparent HTC.

The heat transfer coefficient was calculated from the modified Fourier equation:

$$HTC = \frac{Q,total}{A * dT}$$

where:

HTC = apparent heat transfer coefficient, $kW/(m^2 {}^\circ C)$
A = surface area ($m^2$)
Q,total = Q,v + Q,h = rate of heat energy transfer (kW)
Q,v = rate of energy transfer from latent heat (vapour flowrate x latent heat of vapour)
Q,h = heat required to heat juice to boiling point
dT = Ts – Tj,out = temperature difference across the heat transfer surface
Ts = steamside temperature, °C
Tj,out = juice temperature out, °C

The juice outlet temperature was calculated by adding the saturated steam temperature at the measured vapour pressure to the boiling point elevation at the exit brix. The formulae used to calculate the properties needed to obtain the HTC from the measured data are those recommended by Peacock (1995) and have been given in detail elsewhere with respect to this work (Friedrich, 1995).

*Treatment of the factory measurements*

The plate evaporator did not run continuously due to several stops because of cane shortages. Therefore the operating conditions were not always able to be kept steady and consequently the HTC values calculated from the data obtained were found to vary widely. Taking an average of all HTC calculated results will give some idea of the performance but is of limited value. To make a meaningful assessment of the information obtained, the data were 'filtered' in such a way that the HTC was measured under similar conditions of flowrate, delta T and brix. Repeating this process so that only one parameter was varied at a time, the other parameters effectively being constant, enabled variations of performance to be examined with respect to operating conditions.

## Results

*PE HTC measurements*

Using all data collected over the total time of operation, the average apparent HTC, obtained from the brix balance, was 3,46 kW/(m$^2$°C), and the average HTC from the condensate flow rate measurement (HTC,cond.) was 3,51 kW/(m$^2$°C). The variations in the measured and resulting calculated values are given in Table 3. The HTC values measured under similar operating conditions are shown graphically in Figure 4, which also shows an average for the HTC taken over each 50 hour period. This suggests a decline in the HTC from about 4,1 to about 3,5 kW/m$^2$°C over the 400 hours of operation. The range of 'similar' operating conditions is shown in Table 4.

**Table 3**

**Summary of all data collected**

| Parameter | | Average | Minimum | Maximum |
|---|---|---|---|---|
| Steam pressure | kPa(g) | 22,1 | 0,0 | 45,0 |
| Vapour pressure | kPa(g) | -2,7 | -21,6 | 15,0 |
| Juice flow rate | kg/h | 54 631 | 18 108 | 70 949 |
| Condensate flow rate | kg/h | 17 186 | 7 560 | 40 190 |
| Feed juice temperature | °C | 99,5 | 94,0 | 104,0 |
| Brix in | % | 19,90 | 14,07 | 24,91 |
| Brix out | % | 28,87 | 19,96 | 41,56 |
| Brix out – brix in | % | 8,97 | 4,03 | 19,18 |
| Delta T | °C | 5,7 | 1,8 | 11,3 |
| Heat transfer/m$^2$ | kW/m$^2$ | 18,61 | 7,61 | 28,21 |
| HTC (apparent HTC) | kW/(m$^2$°C) | 3,46 | 1,11 | 6,50 |
| HTC (condensate side) | kW/(m$^2$°C) | 3,51 | 1,26 | 6,60 |

**Table 4**

**Input and calculated values for the apparent HTC measured under similar conditions**

| Parameter | | Average | Minimum | Maximum |
|---|---|---|---|---|
| Total time | hours | 203 | 108 | 393 |
| Steam pressure | kPa(g) | 22 | 15 | 28 |
| Vapour pressure | kPa(g) | -2 | -9 | 6 |
| Juice temperature out | °C | 91 | 75 | 102 |
| Juice flow rate | kg/h | 60 338 | 55 957 | 64 582 |
| Feed juice temperature | °C | 100 | 98 | 102 |
| Brix in | % | 20 | 18 | 21 |
| Brix out | % | 29 | 24 | 32 |
| Calculated values | | | | |
| Steam temperature | °C | 106 | 104 | 107 |
| BP water at vapour pressure | °C | 100 | 98 | 102 |
| BPE (average) | °C | 0,5 | 0,4 | 0,6 |
| Temperature juice side | °C | 100,0 | 98,1 | 102,2 |
| Delta T | °C | 5,5 | 4,6 | 6,3 |
| Heat transfer/m$^2$ | kW/m$^2$ | 21,0 | 14,9 | 23,5 |
| HTC (apparent HTC) | kW/m$^2$°C | 3,9 | 3,2 | 4,7 |
| HTC (steam side) | kW/m$^2$°C | 3,8 | 2,4 | 6,6 |
| Brix out – brix in | % | 9 | 5 | 11 |

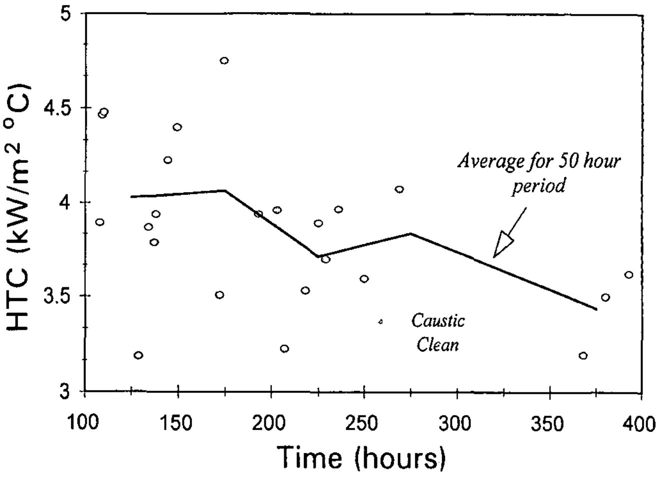


**FIGURE 4:** Variation of the apparent HTC with time where the HTC is measured under similar conditions.

*The effect of operating conditions on the HTC*

When the data were selected so that delta T was 'varied' and other parameters were kept constant, the HTC was seen to fall with increasing delta T, and this is shown in Figure 5.

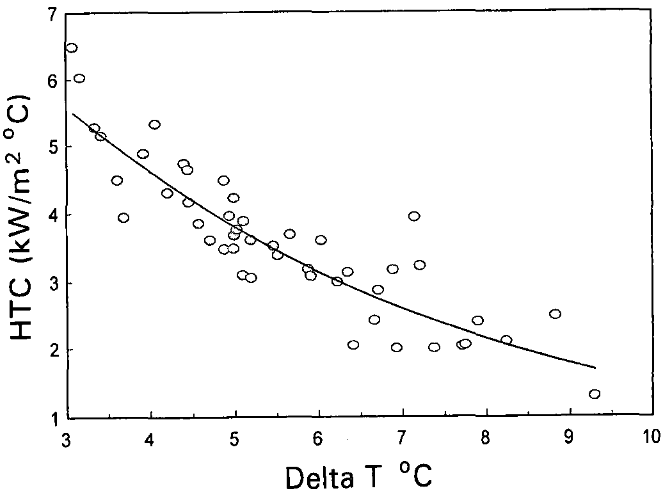


**FIGURE 5:** Variation of the apparent HTC with delta T where all parameters, except delta T, are selected to reflect similar conditions of operation.

**Table 5**

**Values used to consider the variation of the apparent HTC with dT, measured under similar conditions**

| Parameters | | Average | Minimum | Maximum |
|---|---|---|---|---|
| Steam pressure | kPa(g) | 21 | 0 | 40 |
| Vapour pressure | kPa(g) | -4 | -22 | 15 |
| Juice flow rate | ton/h | 55 | 50 | 60 |
| Feed juice temperature | °C | 99 | 96 | 102 |
| Brix in | % | 20 | 16 | 23 |
| Brix out | % | 29 | 25 | 33 |
| Delta T | °C | 5,6 | 3,1 | 9,3 |
| Heat transfer/m$^2$ | kW/m$^2$ | 18,6 | 12,0 | 28,2 |
| HTC (apparent HTC) | kW/m$^2$°C | 3,6 | 1,3 | 6,5 |
| HTC (steam side) | kW/m$^2$°C | 3,5 | 1,8 | 5,4 |

The variation of the parameters used in this calculation are shown in Table 5. When this process was repeated, using flowrate and brix as the varied parameters, no obvious relationship could be found. This probably indicates that only delta T was varied sufficiently during the operation to enable a noticeable change in HTC.

*The effect of fouling on the HTC*

Although the PE operated for only a short time, the HTC change due to scale formation can be estimated from the data in Figure 4. The degree of fouling can be quantified, in terms of the fouling resistance, by the following equation which relates the HTC measured at a particular time to the fouling resistance:

$$1/U(t) = 1/U(0)+Rf$$

where U(t) is the HTC after the evaporator has operated for a time t, U(0) is the initial HTC when the evaporator is clean, and Rf is the fouling resistance. Traditional models hold that the fouling resistance will increase with time, and the HTC will fall accordingly, approaching an asymptotic value. While such a curve is not clearly seen in Figure 4 the data can still be used to make an estimate of the fouling resistance over the 400 hours of operation. If the HTC is considered to fall from about 4,1 $kW/m^{2}°C$ to about 3,5 $kW/m^{2}°C$, a rough value of Rf can be calculated to be 0,05 $m^{2}°C/kW$. This compares favourably with fouling resistance values obtained using the Felixton pilot plant (0,1 to 0,3 $m^{2}°C/kW$ ) (Walthew, 1996a) or calculated from Sezela Kestner HTC data gathered by Patel (1993) of between 2,5 and 3,0 $m^{2}°C/kW$.

*Cleaning*

The PE was cleaned after about 370 hours of operation using a 22% (m/m) sodium hydroxide solution circulated at 90°C for four hours. The sodium hydroxide was fed in reverse flow, that is the caustic solution was pumped to the outlet of the PE (at the top of the plate) and allowed to run down the plates back to the caustic tank via the juice inlet line. At the end of the season the plate evaporator was cleaned once more with a 20% (m/m) caustic solution at 95°C for four hours, and then opened to check the effect of the cleaning. From Figure 4 it would appear that the first cleaning did not result in a significant improvement in the HTC, either because the degree of fouling was minimal or because the cleaning procedure followed was not effective. Possible reasons for inadequate cleaning could be seen when the PE was opened and examined after the second cleaning, when the following were noted:

- The plates showed a thin red/brown and sometimes greyish scale, unevenly distributed over the plate, and it appeared that only one side of the plate had made contact with the cleaning solution. Thus it is assumed that the caustic solution flowed from the upper opening, ie the juice and vapour outlet, down to the opening at the bottom, ie the juice inlet, with a consequent inadequate wetting of the plate. Some accumulated scale was found along the gasket of the PE.
- It was also probable that the water flushing following caustic cleaning did not remove the loosened scale sufficiently. The water was pumped in as for the caustic solution, that is from top to bottom, again with inadequate wetting and flushing.
- A small amount of brown mud was found at the bottom, where the opening for the juice inlet is located. This was probably introduced through the river water used for the flushing operation.
- Close examination of the plates suggested the presence of two types of scale: a soft, easily wiped off, mud-like material (designated 'soft') and a harder, lighter coloured scale which was more tenaciously attached to the plates (designated 'hard'). It should be noted that the amount of 'hard' scale was considerably less than the amount of 'soft' scale. The total amount of scale could not be considered excessive, especially considering that the intermediate and final cleaning operations were probably ineffective.

*Scale composition*

Prior to the installation of the PE, scale samples were taken from the GD evaporators at the end of the 1994 season and these, along with the 1995 season samples of hard and soft scale, described above, were analysed. The results of these analyses are summarised in Table 6. Details of the methods of analysis and calculation of the composition have been described elsewhere (Walthew, 1995; Walthew, 1996 a and b). Overall the scale obtained from the PE showed a significant increase in the amount of phosphate present compared with previous samples taken from the GD second effect. The calcium phosphate was present as amorphous calcium phosphate (ACP) and as a well crystallised, hydroxyl apatite (HAP), $Ca_{10}(OH)_2(PO_4)_6$(HAP). The other species of interest was amorphous silica, which in the case of the hard scale was high for a second effect. A trace amount of quartz (sand) was found in the soft scale sample along with some mica and clay, confirming that there was some contamination from the wash water. Interestingly no calcium oxalate, either as the monohydrate (COM) or the dihydrate (COD), was found in the scale from the PE.

Comparison of the hard and soft scale components suggests that there is no difference in the inorganic composition, except that the soft scale contained some clay and mica origi-

**Table 6**

**Analysis of GD scale showing the estimated composition**

| Compound | HAP | ACP | $MgO.H_2O$ | $SiO_2.H_2O$ | COM | COD | Mixed oxalate | Lime hydrate | Amorphous organic |
|---|---|---|---|---|---|---|---|---|---|
| Hard | 38 | 22 | 7 | 16 | 0 | 0 | 0 | 13 | 4 |
| Soft | 36 | 21 | 3 | 13 | 0 | 0 | 0 | 15 | 13 |
| Previous: | | | | | | | | | |
| 1st effect | 26 | 30 | 3 | 1 | 0 | 0 | 0 | 0 | 40 |
| 2nd effect | 0 | 36 | 6 | 8 | 2 | 0 | 0 | 17 | 32 |
| 3rd effect | 0 | 2 | 1 | 7 | 60 | 0 | 0 | 18 | 14 |
| 4th effect | 0 | 1 | 0 | 28 | 0 | 0 | 40 | 16 | 16 |

nating from river mud. Of importance, however, is the reduction in the calculated organic content of the hard scale, since the organic fraction is the component which makes the scale soft and susceptible to sodium hydroxide cleaning. It can be concluded therefore that the lighter, harder scale was probably 'aged' and dehydrated soft scale. It may also be an indication that the turbulence at the plate surface, and hence the flowrate, were less than optimum but this would need further investigation.

*Comparison with HTC data from other evaporators*

While the PE was cleaned with sodium hydroxide, the remaining evaporators continued to operate. To compare the performance of the Roberts vessels with the performance of the plate evaporator, each effect was monitored, without the PE on line and the calculated values of the HTCs are shown in Table 7. The HTC was calculated using brix and flowrate measurement, as done when evaluating the PE. In Table 8 the HTCs from various sources (Roberts and Kestner evaporators) are given (Rein and Love, 1995; Hugot, 1986; Nilsson, 1994). These last two tables suggest that the HTCs for the first, third and fourth vessels at GD are low by comparison with the industry and that the PE performance is significantly higher than either Kestner or Roberts vessels in the industry. Furthermore it would appear that the PE is performing at about the level expected from the work reported by Nilsson (1994). A comparable plate evaporator installation in Australia, where an EC500 PE was configured as a second effect operating as a booster, has been described by De Viana *et al.* (1993). The flowrates for that installation were about 15 t/h per 100 $m^2$ of heating surface compared with 11 t/h per 100 $m^2$ of heating surface for the GD installation. De Viana *et al.* (1993) report an HTC of about 3,7 $kW/m^{2\circ}C$ for the clean unit and 2,8 $kW/m^{2\circ}C$ when fouled (after about 250 hours of operation). This corresponds to a fouling resistance of about 0,09 $m^{2\circ}C/kW$.

**Table 7**

**Apparent HTC for Roberts evaporators at Glendale mill, without the PE in operation**

| Effect GD mill | App. HTC $kW/(m^{2\circ}C)$ | | |
|---|---|---|---|
| | Average | Minimum | Maximum |
| 1A | 1,3 | 1,1 | 1,8 |
| 1B | 1,6 | 1,0 | 2,2 |
| 1C | 1,1 | 0,5 | 1,6 |
| 2 | 1,9 | 1,3 | 3,5 |
| 3 | 1,5 | 0,8 | 2,1 |
| 4 | 0,8 | 0,6 | 1,1 |

**Table 8**

**HTC values for various evaporators reported in the literature**

| Effect | Apparent HTC $kW/(m^{2\circ}C)$ K=Kestner; R=Roberts; PE=Plate evaporator | | | | |
|---|---|---|---|---|---|
| | Rein and Love | Hugot | GD mill | PE at GD | Nilsson |
| 1 | 2,3 K | 2,5 K/R | 1,3 R | | 4,5 PE |
| 2 | 1,8 K | 1,8 K/R | 1,9 R | 3,5 PE | 4,0 PE |
| 3 | 1,7 R | 1,4 K/R | 1,5 R | | 3,0 PE |
| 4 | 1,4 R | 0,8 K/R | 0,8 R | | 2,2 PE |
| 5 | 0,7 R | | | | |

## Conclusions

Overall the performance of the PE has been encouraging, with relatively high HTCs being measured and apparently low rates of fouling compared with existing tubular evaporators. The PE installed at GD appears to be performing at about the same level as the installation studied by De Viana *et al.* (1993), and in the range expected from the manufacturers. It is interesting that one of the conclusions made by De Viana *et al.* (1993) is that the HTC is optimised by running at about 15 t/h per $m^2$ of heating surface which is significantly higher than that currently used at GD. This, coupled with the information obtained from the scale analysis, suggests that the flowrates at GD should be increased. While encouraging, these results were obtained during a short and unusual season, and further monitoring during the 1996 season will be necessary.

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### REFERENCES

De Viana, MJ, Broadfoot, R, Cope, A and Dephoff, RM (1993). Performance evaluation of a plate evaporator. *Proc Aust Soc Sug Cane Technol* 15: 132-140.

Fredrich, C (1995). Glendale climbing film evaporator. Sugar Milling Research Institute Technical Note 46/95, 24 pp.

Hugot, E (1986). *Handbook of Cane Sugar Engineering.* Elsevier, Amsterdam: 572-573.

Nilsson, I (1994). Industrial Plate Evaporators. *Proc S Afr Sug Technol Ass* 68: 125-127.

Peacock, SD (1995). Predicting physical properties of factory juices and syrups. *int Sug J* 97(1162): 571-577.

Rein, PW and Love, DJ (1995). Experience with long tube climbing film evaporators. *Proc int Soc Sug Cane Technol* 22: (in press).

Walthew, DC (1995). Evaporator fouling literature review. Sugar Milling Research Institute Communication No. 159, 83 pp.

Walthew, DC (1996a). A general procedure for the analysis of evaporator scale. Sugar Milling Research Institute Technical Note No. 4/96, 8 pp.

Walthew, DC (1996b). Analysis of scale from the plate evaporator at Glendale. Sugar Milling Research Institute Technical Note No. 8/96, 7 pp.