# EXPERIENCE WITH PLATE EVAPORATORS AT UBOMBO RANCHES IN SWAZILAND

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## Abstract

Ubombo Ranches converted its evaporator station from a quadruple to a quintuple configuration in 1996. Existing vessels were rearranged and plate evaporators incorporated in two effects. Facilities were also installed to measure and record heat transfer coefficients on a continuous basis, to enable the monitoring and detecting of a drop-off in performance. During the first two seasons, many operational problems were encountered which necessitated major modifications and changes to the plant and its operating procedures. After many trials, a chemical cleaning regime for descaling of the evaporators was developed and adopted with reasonable success.

## Introduction

As part of an expansion programme and a drive for energy efficiency, Ubombo Ranches changed their evaporator station in 1996 from a quadruple to a quintuple configuration and increased vapour bleeding. The new evaporator layout is shown in Figure 1.

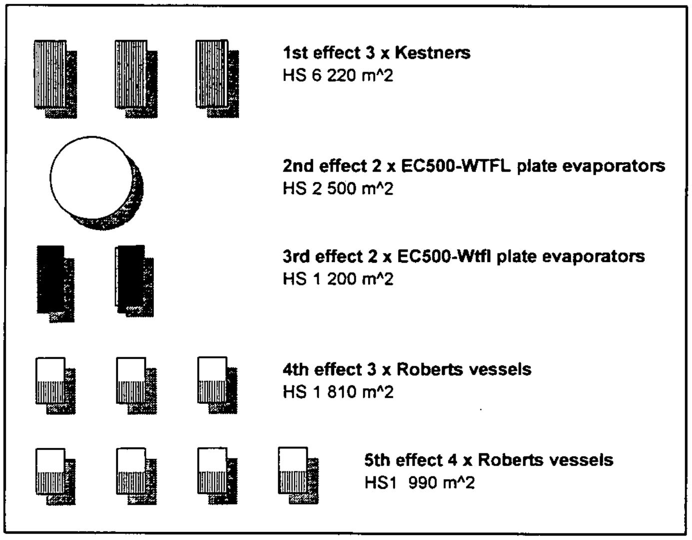

**Figure 1.** Ubombo Ranches Limited evaporation station layout.

The new layout consists of:

- First effect: three semi-Kestner, long tube rising film evaporators with a total heating surface of 6 220 m$^2$
- Second effect: two new EC500-WTFL plate evaporators installed in parallel, inside a vessel. Their combined heating surface is 2 500 m$^2$
- Third effect: two new EC500-WTFL plate evaporators with external vapour separators. The combined heating surface of this effect is 1 200 m$^2$
- Fourth effect: three Robert short tube evaporator vessels with a heating surface of 1 810 m$^2$
- Fifth effect: four Robert vessels with a total heating surface of 1 990 m$^2$.

In all five effects the juice is introduced in series and the steam in parallel.

Mixed juice heating is achieved in four stages:

- Initially with a 239 m$^2$ MA30-SFM wide gap plate heat exchanger on $V_4$. This is fitted with automatic reverse juice flow, changing juice flow direction at 120 minute intervals
- 273 m$^2$ MA30-SFM wide gap plate heat exchanger on $V_3$, also fitted with automatic reverse juice flow
- Three shell and tube heaters installed in series and heated with $V_2$. These have a total heating surface of 742 m$^2$
- The final mixed juice heating takes place with a 232 m$^2$ shell and tube unit on $V_1$, fitted with automatic temperature control.

Because of the high pressure drop across the heaters, an intermediate pump was installed after the first shell and tube heaters.

Clear juice heating is carried out with two plate heat exchangers operated in series.

- The first is a 139 m$^2$ AM20-FM plate heat exchanger heated with $V_1$
- The second is a 64 m$^2$ AM20-FM plate heat exchanger on exhaust steam.

In addition to vapour bleeding for mixed juice heating, $V_2$ steam is also used in the diffuser scalding juice heaters and for the B and C continuous pans.

## Description of plate evaporators

In appearance and operation, plate evaporators are not very different from the more familiar plate heat exchangers. The main difference is the profile of the plates and the size of inlet and outlet ports. Plates are welded together in pairs and are referred to as cassettes. The gap between the plates provides a passage for the steam and condensation. Rubber gaskets inserted between adjacent cassettes provide channels for the juice to flow through. Cassettes are clamped together between two pressure plates. The C500 units installed at Ubombo

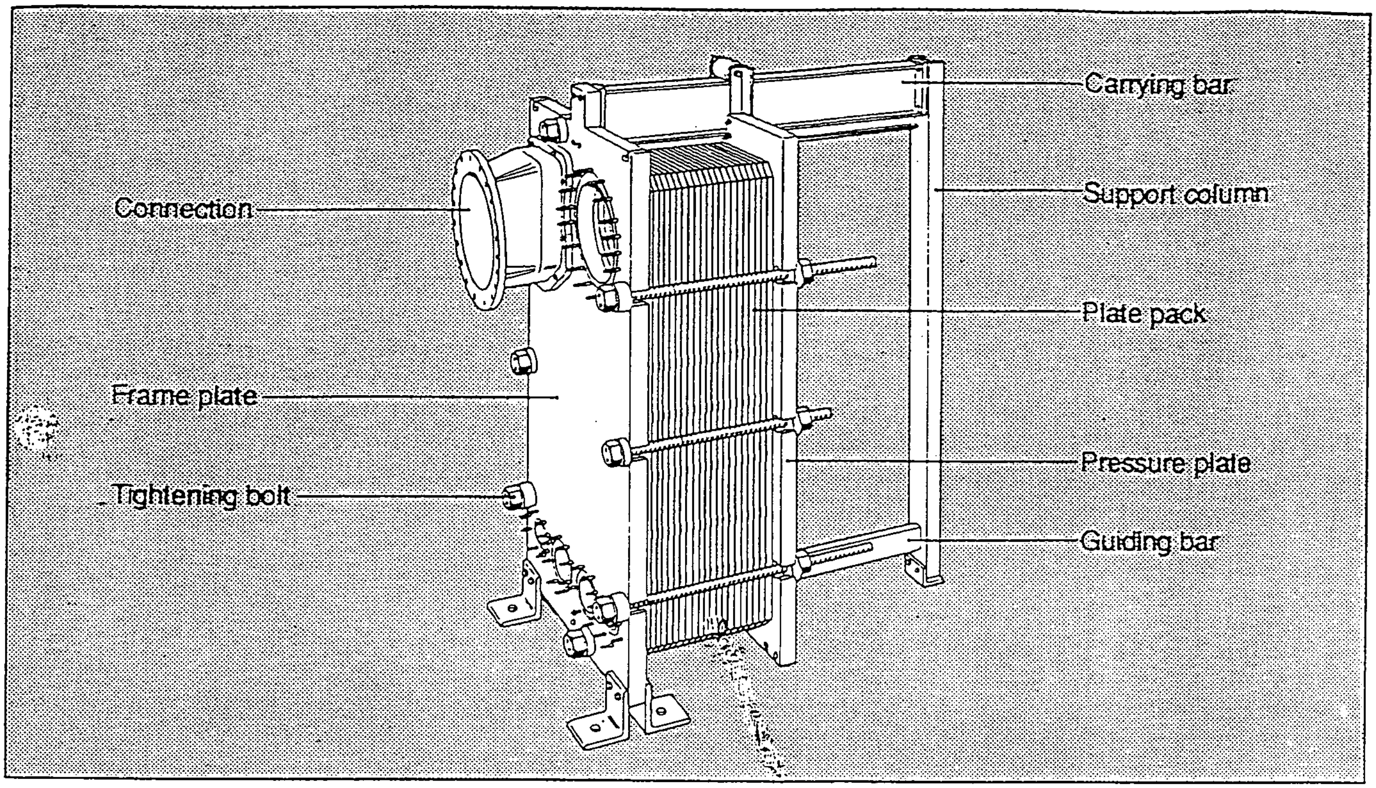

**Figure 2.** Typical plate evaporator.

have plates of approximately 1x2 m in dimension. The 2nd effect is made up of two units in parallel, each with 475 cassettes and 6 270 mm long installed inside a vessel acting as a vapour separator. The 3rd effect is made up of two units each with 230 plates and 3 036 mm long with an external vapour separator. Juice is introduced into the bottom of the pack from a pre-evaporator flash tank. Juice rises up the plates and the two phase liquid exits from the top. Because of its length, and to prevent excessive port velocities the second effect outlet ports are cut away allowing juice to discharge directly into the surrounding vessel. The two phase liquid from the 3rd effect discharges from both ends of the pack and tangentially enters an external vapour separator. About 75% of the inlet ports of the plates are restricted to provide better distribution of the juice along the full length of the pack.

The plate evaporators were selected on the following criteria:

- They are easy to expand. Additional plates can be added to increase the heating surface without major construction changes.
- Shorter juice retention lead to lower colour formation, sugar inversion or degradation.
- The high heat transfer coefficients (HTC) claimed, require less heating surface for the equivalent evaporation, when compared with conventional tubular units.
- Compact designs use less material and therefore should result in lower capital cost.

At the time of ordering the plate evaporators, there were already 91 units in operation in the beet industry and 58 units with a total heating surface of 25 871 m$^2$ in the cane industry. Reorders of units had apparently been coming in.

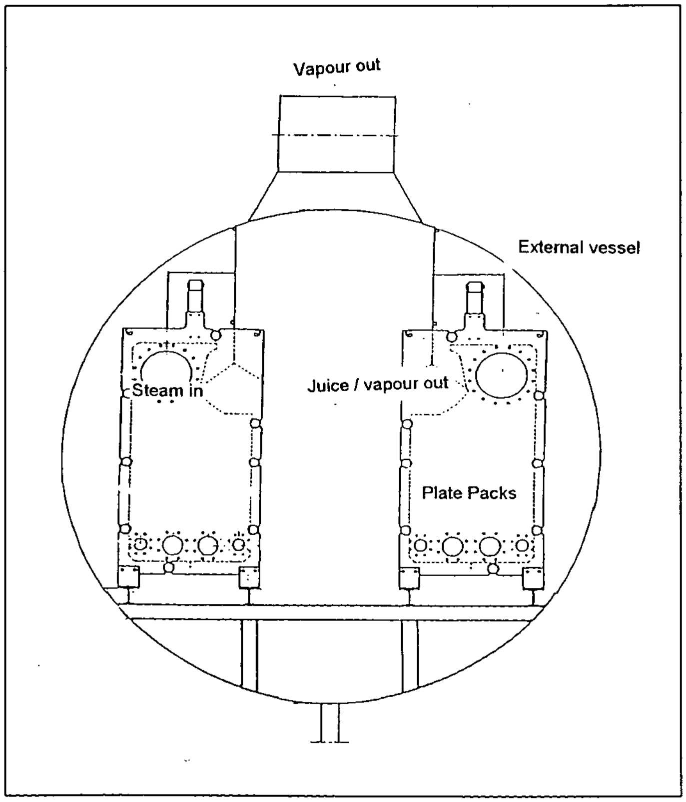

**Figure 3.** Second effect (plate pack inside a vessel).

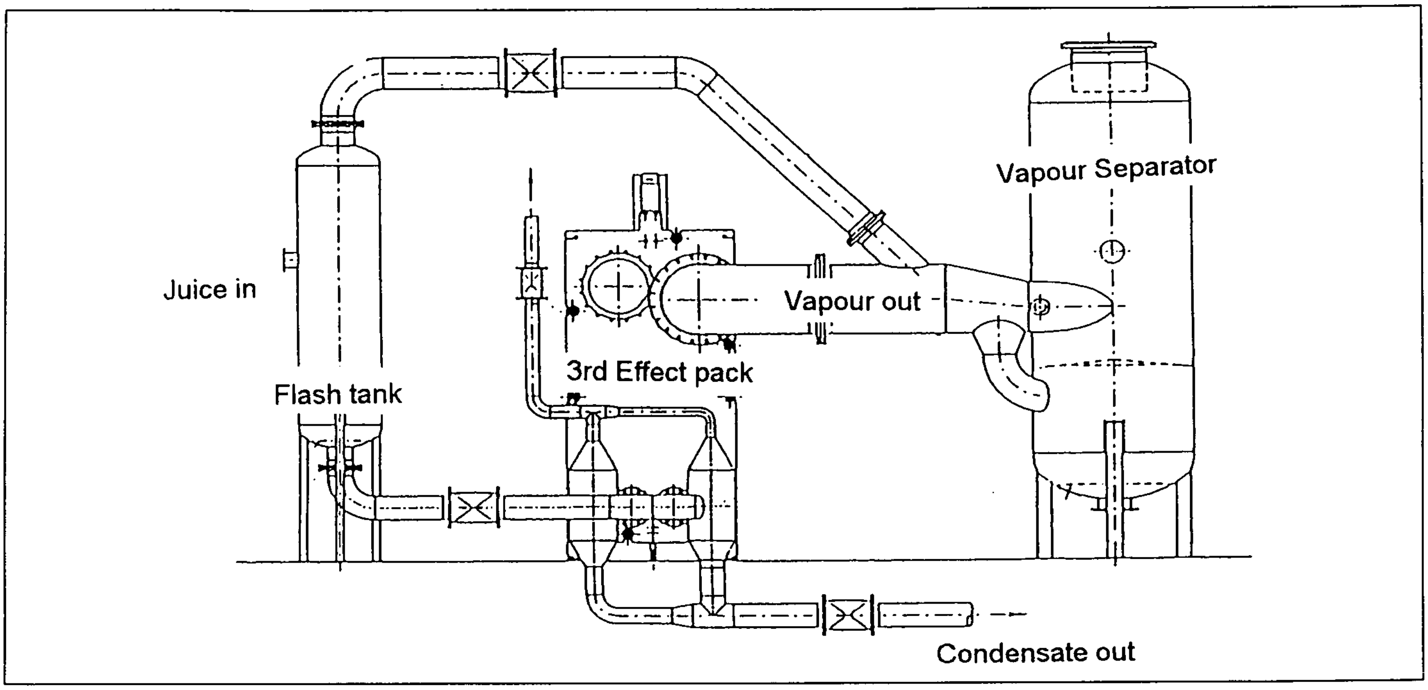

**Figure 4.** Third effect with external vapour separator.

### Initial protection circuits

At the outset the suppliers advised that every precaution must be taken to ensure that the minimum flow of 150 litres per channel per hour to the evaporators must always be exceeded. Following their recommendation, the clear juice flow control was introduced to ensure that a steady flow of clear juice, above this minimum required level, was continuously supplied to the 1st effect. This flow took into account the evaporation from the 1st and 2nd effects and still supplied sufficient juice to the 3rd effect. In the event of there being insufficient clear juice to maintain the required flow, or when the clear juice tank level ran low, water was automatically introduced into the clear juice tank. Excess condensate was the first source of water supply for this make-up, supplemented by raw water when insufficient condensate was available.

### Operational experiences

The weakness of this protection feature was not initially obvious, and it was only when problems occurred in tuning the level control which was installed to maintain a seal between the first two effects, that it became apparent that the flow between the 1st and 2nd effects was far from steady, despite a steady clear juice flow into the first Kestner. Initially, after commissioning, the operation seemed to be satisfactory, but shortly thereafter there was a steady drop-off of syrup brix which necessitated that the throughput had to be cut back. The performance steadily deteriorated until, after about 10 weeks, there was no alternative but to shut the evaporators down completely, split the packs and physically clean the units. The plates were found to be very badly fouled. The upper parts of the ports were scaled up, reducing the flow rate through the evaporators, which resulted in sugar caramelising and totally blocking many of the channels. Initially one pack was cleaned and reassembled by working around the clock for four days and nights. The second pack was brought on line some weeks later during an extended scheduled stop.

After the first big clean up, it was evident that the low feed to the plate evaporators and the resulting scale burn-on was the major contributing factor of the bad fouling experienced. To get going and to act as a stop-gap, two plant modifications were made in an attempt to prevent the recurrence of the fouling.

- A buffer tank was installed between the 1st and 2nd effects to prevent the pulsating flow of juice.
- A clear juice connection was installed from the delivery of the clear juice pump to the inlet manifold of the 2nd effect. A non-modulating control valve was installed in this line to control the juice flow into the 2nd effect. The control valve opened whenever the clear juice flow dropped below a predetermined level, or when the control valve between the first two vessels shut back too much. The flow of make-up was regulated with a manual valve.

It was evident that a triangular section at the top of the plates, above the overflow level, became fouled. This was a section where the caustic solution did not reach during chemical cleaning. On fouling, juice flow below this section was reduced to such an extent that it caused the sugar to burn on. At that stage the suppliers insisted that the caustic was not to be boiled in the packs to prevent the concentration from rising too high and causing caustic embrittlement (caustic induced stress corrosion cracking). After the initial fouling, the cleaning strategy changed and caustic was boiled during chemical cleaning. Careful monitoring of the liquid level was enforced to prevent excessive concentration of the caustic solution.

These modifications were not considered to be a permanent solutions. The relatively small volume of the buffer tank did not totally overcome the pulsating effect of the juice flow. Also, resulting from being over-cautious, the non-automatic regulation of the make up to the 2nd effect often introduced too much juice or water, which resulted in slack syrup. However, the plant operated in this manner for the remainder of the season, during which time careful monitoring of the operation led to the necessity for further modifications before the start up of the second season.

### Modifications made after first season of operation

During the first off-crop, the following modifications were carried out (see Figure 2):

- The bottom of 1C Kestner separator was extended and the small buffer tank removed to increase the buffer volume between the first two effects.
- A pump was installed to circulate juice around the 2nd effect. This ensured a high juice flow through the packs at all times, keeping the plates wet.
- Juice and steam was introduced into both ends of the pack.
- Condensate was extracted from both ends. Large condensate pots with sight-glasses were fitted to verify proper drainage and separation of condensate and incondensable gas.
- Because of high carry-over and contamination of the condensate of the 3rd effect, the entrainment separator of the 2nd effect was replaced with a louver type unit.

### Control philosophy adopted for second season

Several changes to the control philosophy were introduced during the second season:

- Because of the inadequate clear juice tank buffer capacity, steady clear juice flow was obtained by fluctuating the level in the mixed juice tank at the expense of proper clarification operation.
- When the flow between the 1st and 2nd effects dropped below 160 m$^3$/h the clear juice make-up opened into the 2nd effect. The sum of the juice flow between the first effects and make-up was maintained at 160 m$^3$/h, which equated to more than the minimum 150 litres/pass/hour stipulated by the suppliers.
- Also when the flow to the 3rd effect dropped below 80 m$^3$/h, make-up came in.
- When the level in the clear juice tank dropped to 20%, make-up water was introduced to the clear juice tank. The valve shut again when the level reached 30%.
- It was also necessary to install a facility to isolate one plate pack on the run in the event of extended interruptions of juice availability, such as when one of the two extraction plants went off. The isolation was initiated remotely from the DCS, where the operator was in constant communication with the extraction plant operators. When one pack was isolated, the set points of the flows to the 2nd and 3rd effects was halved.

### Chemical cleaning

Chemical cleaning is absolutely essential for routine cleaning of the plate evaporators because physical cleaning takes too long and gaskets are damaged each time they are disturbed. The price of a full set of gaskets in 1996 was quoted at over R0,75 million. The chemical cleaning programmes went through many stages and numerous trials before the current procedure was eventually settled on.

- Evaporator cleaning stops are scheduled fortnightly.
- When the juice stops, the vessels are de-sweetened by displacing the juice with water.
- Water is then boiled for at least an hour.
- The water is then replaced with a 15% caustic soda solution containing 0,5% by volume of wetting agent. This is circulated and boiled for six hours.
- Condensate from the effect is returned to the vessel to maintain a constant caustic strength.
- Caustic is introduced into the 2nd effect then circulated to the 3rd effect and then returned back to the 2nd effect again.
- The caustic is then drained from the evaporators and replaced with water, which is boiled once through for a further hour, then the steam is isolated.
- Flushing out of the vessels with water is maintained until the pH of the discharge water drops to below 9. This takes another two hours.
- Phosphoric acid (10-15%) containing 1-2% inhibitor is then circulated through the packs for at least two hours.
- Finally, the packs are again rinsed out with water before they are ready to be put back on line.
- The 3rd effect outlets were fitted with butterfly valves with the top half of the disk removed. This raises the level of the chemical being circulated and ensures that the whole plate is flooded.
- While the plate evaporators are chemically cleaned, caustic is boiled in the tubular vessels to soften the scale. These vessels are, however, still cleaned mechanically.

### Operation of second season

There was an improvement in the operation during the 1997 season and generally the HTCs were restored after cleaning. The performance of the evaporator station was acceptable although still not trouble-free. When the make-up demand was high because of a low flow between 1st and 2nd effects, the flow to the Kestners dropped off and starved the vessels, which further reduced the flow from the 1st effect. This called for more make-up and eventually required water to be introduced directly into the Kestners to control exhaust steam pressure. This was overcome by restricting the clear juice control valve from shutting back more than 30%. There were occasions that the level in the 1st effect separators rose and juice carried over into $V_1$. It was therefore necessary to install high level alarms on the Kestner separator.

During the latter part of the season about 70 plates of the 2B vessel, which was occasionally isolated, appeared to be blocked. This number doubled by the time of boil-off. The cause of this was that the steam valve liner was damaged and the steam was not properly isolated when the pack was isolated. A 50 mm bypass was then installed round the juice valve to ensure that the pack did not dry out when isolated. There is a facility to return slack syrup to the clear juice tank, but this option must be controlled with extreme caution.

During the season, the 3rd effect had to be opened twice to physically clean the plates due to a drop-off in performance. This effect can be taken off line on the run without too much disruption and can be physically cleaned in crop. It is possible that this effect is somewhat ignored in comparison to the 2nd effect.

On stripping the plates after the second season of operation, it was evident that the 2B pack, with the facility to be isolated on the run, was badly fouled and many of the passages were totally blocked, particularly in the middle of the pack. The 2A pack on the other hand was reasonably clean and had few blocked passages. On the 2B pack the areas above the blocked ports fouled up and caused about 30% of the heating surface of the plate to be inoperative. Another problem that became evident during the cleaning operation was that flakes were dislodging from the surfaces and were circulating in suspension with the chemicals. When a large flake lodges itself in a passage, smaller flakes accumulate behind it and eventually block the passage. Work is being done to develop a filter to screen out all flakes during the chemical cleaning process.

### Performance measuring and monitoring

After the first major fouing, it became obvious that it was necessary to monitor the performance of the plate packs continuously, to detect any fall-off in performance. It was decided to calculate the heat transfer coefficient (HTC) of the first three effects by measuring and recording condensate flows from the effects with an orifice plate and DP cell. Steam pressures in and out were also recorded. The results are printed out daily on the DCS and then transferred to a spreadsheet, and the HTCs are calculated and presented graphically. Typical HTC figures obtained are illustrated in Figure 5.

This information proved to be extremely valuable. It indicated how effective the cleaning process was and assisted in deciding when to initiate a schedule cleaning. The calculation of HTC is as given in Appendix 1. Typical HTCs recorded are given in Table 1.

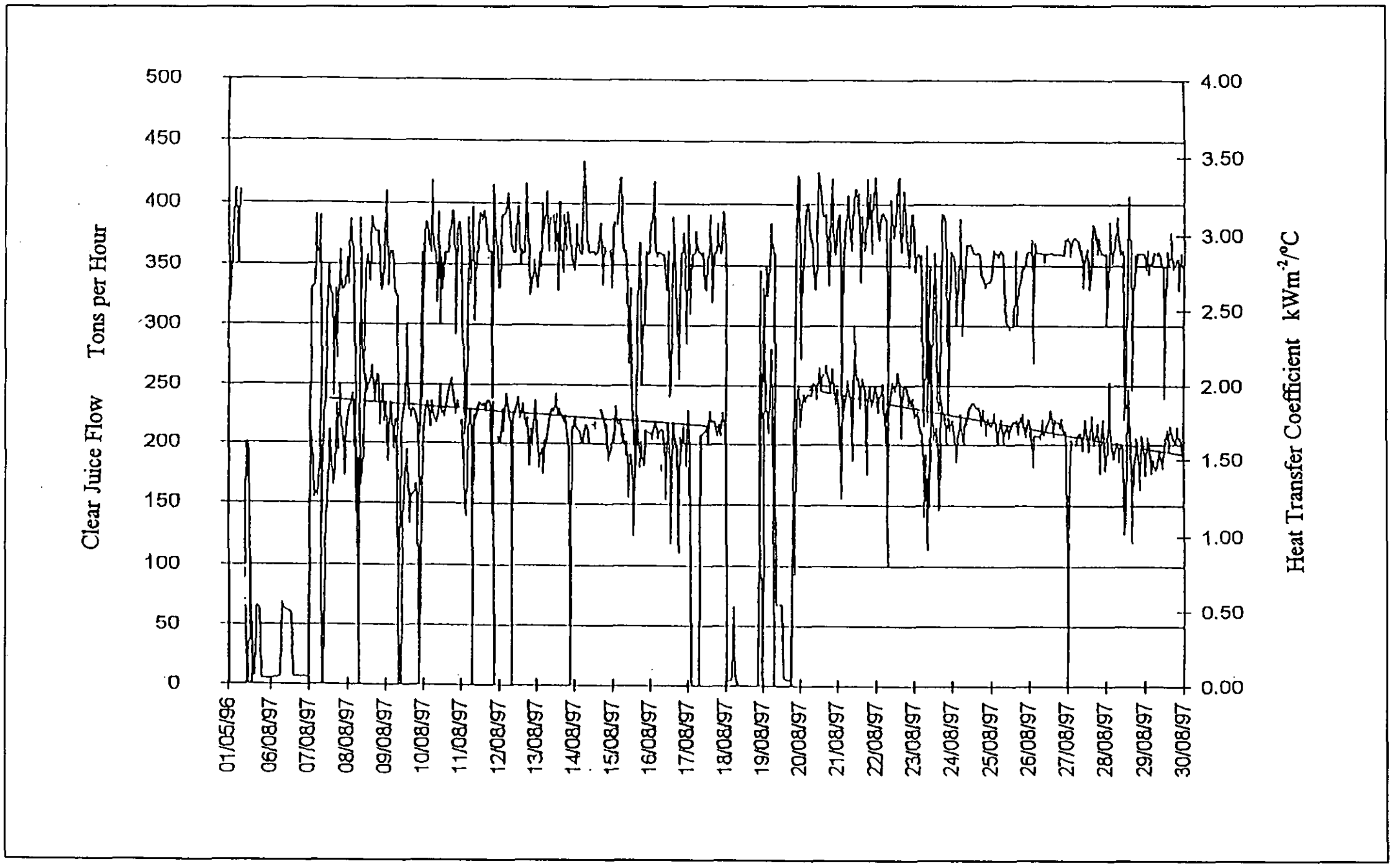

**Figure 5.** Typical heat transfer coefficient and juice flow of second effect.

**Table 1. Heat transfer coefficients.**

| Evaporator effect | Design HTC | Typical HTC |
|---|---|---|
| First effect | 2,3 | 1,8 |
| Second effect | 3,3 | 2,5 |
| Third effect | 2,3 | 1,5 |
| Fourth effect | 0,7 | 0,6 |
| Fifth effect | 0,3 | 0,5 |

## Conclusions

After two seasons of operation, and with plenty of valuable practical experience gained, the evaporator station is still not totally trouble free and will still need a great amount of attention. It may well require further modifications, both to the method of operation and possibly to the physical construction and layout, before all the problems are resolved.

## APPENDIX 1
### Calculation of heat transfer coefficient

$$\mathrm{HTC} = \frac{Q}{A * dT}$$

where :

HTC = Apparent heat transfer coefficient, $kW/m^2$ °C

A = Heating surface area, $m^2$

Q = Rate of heat energy transfer from latent heat (calandria condensate flow rate + flash) x latent heat of vapour

dT = Ts – Tj
= Temperature difference across heat transfer surface

where

Ts = steam side temperature, °C

Tj = juice temperature out, °C.

For the performance testing the following criteria were used:

- Temperature differences were derived from steam tables using absolute pressure of the vapour as measured.

  Absolute pressure = gauge pressure + 99,8 kPa (allowing for 133 m altitude)

- In the case of juice heaters, the log mean temperature difference (LMTD) was calculated:

  $$\mathrm{LMTD} = \frac{(To) - (Ti)}{\ln\left((Ts - Ti) / (Ts - To)\right)}$$

  where

  To = temperature of juice out, °C

  Ti = temperature of juice in, °C

  Ts = temperature of heating vapour, °C.

- Flash is calculated from a factor F = Flash mass/condensate mass. This is given by:

  $$F = (Tc - Tv) \times 4{,}187 / \text{Latent heat of } Tv$$

  where

  Tc = condensate temperature, °C

  Tv = vapour temperature, °C.

- True condensate flow C1 is calculated from that measured Cm as follows:

  $$Ct = Cm / (1 - F).$$