TESTS ON A PLATE EVAPORATOR PILOT PLANT AT MALELANE

RC LOUBSER[1], P SAHADEO[2] and I SINGH[2]

[1]*Sugar Milling Research Institute, University of Natal, Durban, 4001, South Africa*
[2]*Malelane Sugar Mill, Transvaal Sugar Ltd*

Abstract

A pilot plate evaporator plant using the new AlfaVap 700, together with a controller test rig, was installed at Malelane Sugar Mill. The plate evaporator was first installed in parallel to the first effect then the second and fourth effects. Measurements were taken to determine the heat transfer coefficients. It was found that the values measured in the second effect exceeded those for Roberts vessels operating under similar conditions, while results for the first and fourth effects compared favourably with design values for Roberts vessels.

Although provision was made for chemical cleaning, this was never found to be necessary. For completeness of the study, a chemical clean was performed after the fourth effect test was completed.

In the study it was found that heat transfer coefficients comparable to or better than those achievable with a shell and tube design can be expected using plate heat exchangers. None of the fouling problems previously experienced with plate evaporators were detected while testing the new AlfaVap 700 pilot plant.

Keywords: plate evaporator, Malelane, Alfa Laval EC500, Alfavap700, heat transfer, fouling

Introduction

Although plate evaporators have many advantages over shell and tube designs, such as their compact nature and reported higher heat transfer coefficients, they have not been widely adopted for evaporation of clear juice in the raw house. This is not without good reason. The plate evaporators used in such installations, namely the Alfa Laval EC500 installed within a vessel, suffered from fouling problems.

Since then, Alfa Laval returned to the drawing board to address these problems and has produced the AlfaVap 700. Changes were made to the shape of the evaporator to assist in producing a symmetrical flow and avoiding the dead spots found in the EC500. Modifications were also made to the plate pattern near the gaskets to improve the flow distribution and thereby minimise fouling, so that it was not necessary to replace the gasket set after each opening.

Alfa Laval approached Malelane mill to provide the facility for doing the test, and the Sugar Milling Reseach Institute (SMRI) was requested to act as observer.

Background

Plate heat exchangers and evaporators have some very desirable qualities. They are very compact and are claimed to be more effective than their shell and tube counterparts.

Nilsson (1994) reports heat transfer coefficients as high as 4.5 kW/mºC for the first effect, and Walthew *et al.* (1996) measured 3.5 kW/mºC for the second effect at Gledhow.

These qualities have been demonstrated by numerous tests such as those by Kampen *et al*. (1999), Walthew *et al*. (1996) and Friedrich (1995).

There is, however, another theme that can be found in the literature, namely concerns about fouling (Reid, 1995; Walthew, 1996). These concerns were not without substance, as illustrated by the problems experienced with plate evaporators at Ubombo Ranches (Walthew, 1996; De Beer and Moult, 1998) and juice heaters at Hippo Valley (Walthew, 1997).

Experiment Approach

A 41 m^2 pilot version of the AlfaVap 700 evaporator was installed at the Malelane mill to run in parallel with the evaporator station. The plan was to run the pilot plant in parallel with each effect and monitor its performance. This would allow the factory to operate normally while the test was in progress.

Various parameters including steam inlet pressure, condensate flow rate, product inlet flow rate and temperature, product outlet pressure and temperature, and vapour outlet conditions were calculated using the condensate and brix techniques described in appendix A.

The AlfaVap 700 was first installed in parallel with the first effect and operated for approximately six weeks. Heat transfer coefficients (HTCs) were calculated during this period. Thereafter, it was moved to the second effect, where it was operated for about three weeks. Finally it was moved to the fourth effect, where it operated for about two weeks.

A clean set of plates was used at the start of each effect. As the tests progressed, the operating conditions were adjusted to closely resemble actual operating conditions that may be expected for the AlfaVap 700. Provision was made for chemical cleaning-in-place (CIP), when the HTC dropped. The fouling rate on the first two effects was small. Consequently no CIP was carried out on these effects. Although some drop in HTC was observed in the fourth effect, a point was not reached during the test where it was deemed that a CIP was necessary. At the end of the test on the fourth effect, it was decided to perform a CIP to get an indication of how effective the process would be.

Alfa Laval configured their test rig to perform the test, as shown in Figure 1.

The juice inlet flow rate was measured by flow meter F101 and the temperature by TT101. The pressure of the incoming steam was measured by pressure transducer PT200 and the flow rate of the condensate was measured using flow meter F200. Pressure and temperature of the outgoing vapour was measured by PT101 and TT102, respectively. The temperature of the outgoing juice was indicated by TT103. A pump, P101, was used to force circulation of the juice. F102 measured the amount of juice recirculation.

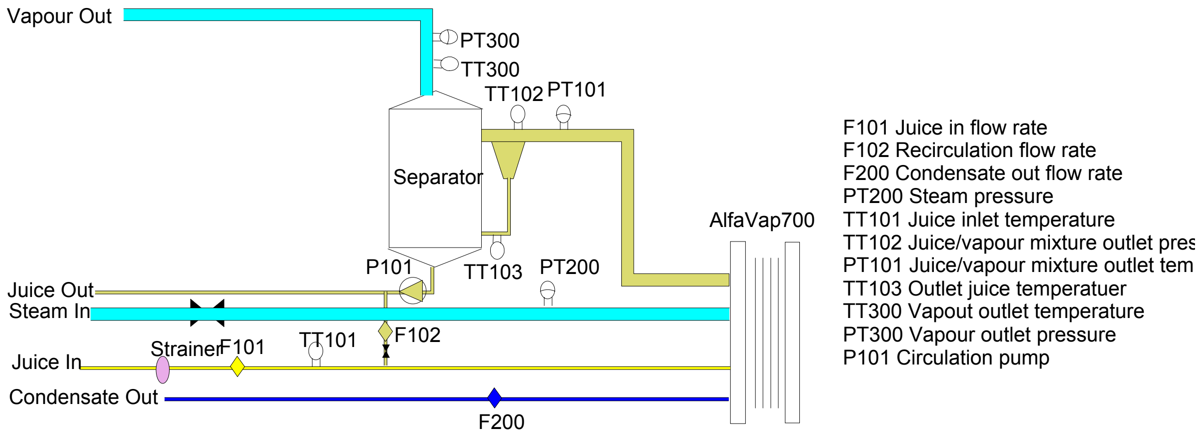

Figure 1. Configuration of the Alfa Laval test rig.

First Effect

Operating conditions

At Malelane, the first effect consists of two stages. Some evaporation is achieved using a Roberts vessel. The output from this is mixed with incoming clear juice before the second stage of the first effect. The AlfaVap 700 was installed in parallel with the second stage; in other words, the entry brix was slightly higher than that of clear juice. Initially, the brix rise across the AlfaVap 700 was considered to be too low, so this was increased during the test. Typical operating conditions are shown in Table 1.

Table 1. Typical operating conditions for first effect.

Brix in	13.0-16.2%
Brix out	15.0-18.5%
Pressure steam	64-114 kPa (g)
Mass flow condensate	1.0-2.5 tons/h
Mass flow feed	6.5-11 tons/h
Recycle	1.9-2.2 tons/h

Results and observations

The main concern in plate evaporator installations is the possibility of fouling. The intention was to perform a chemical CIP after about two weeks, when the HTC started to deteriorate from the value measured under clean conditions. It was, however, never deemed necessary to clean the evaporator during the test. The evaporator was opened after two weeks of operation. A thin layer of soft, gray coloured scale had formed on the surfaces. Although care was taken not to disturb the scale, this pealed away readily and the exposure of areas could not be avoided. From this, it was concluded that a point might be reached where the soft scale formed would balance that which was scoured away by the juice.

Another observation was that the flow pattern was even and radiated out towards the outlet. There was no evidence of dead spots that could cause fouling after extended operation.

The results for the HTC calculated by the two methods is shown in Figure 2.

Although there are slight deviations between the two methods, it is clear that HTCs are comparable to those used for the design of a Roberts vessel of 2.5 kW/m^2 ºC (Love *et al.*, 1999) or 2.6 kW/m^2 ºC (Reid and Rein, 1983). The evaporator was not loaded at full capacity and higher HTCs were expected. The pipe sizes were increased for later effects.

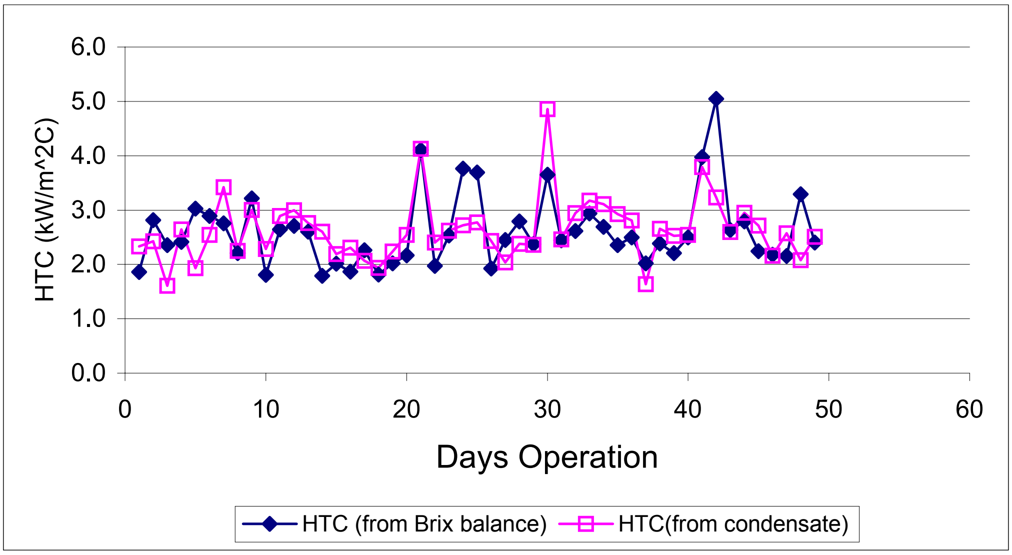

Figure 2. Heat transfer coefficient for first effect.

It is critical to note that the HTC depends on flow velocity, temperature and temperature difference. A pump is needed to ensure that the required flow rate is maintained. An effective control system is required to ensure that the plates remain wet. If the plates are allowed to run dry, severe scaling may occur.

Second Effect

Operating conditions

The AlfaVap 700 was installed in parallel with the second effect. Unlike when it was used in parallel with the first effect, which had a high juice pressure, it was necessary to introduce a pump to ensure an adequate flow rate. Typical operating parameters are shown in Table 2.

Table 2. Typical operating conditions for second effect.

Brix in	24.4-29.5%
Brix out	34.9-44.6%
Pressure V1 steam	27.5-32 kPa (g)
Mass flow condensate	1.0-1.6 tons/h
Mass flow feed	4-8 tons/h
Recycle	1.53-1.63 tons/h

Results and observations

The HTC was found to be higher than that used in the design of shell and tube vessels namely of 2.5 kW/m^2 ºC (Love *et al.*, 1999). Some fluctuation in the HTCs calculated was also experienced. This again highlights that the HTC is a function of operating conditions.

Once again, it was decided that a chemical clean was not necessary for the duration of the test. Some carry-over was detected in the vapour. Although this is a function of the separator rather than the plate pack, it remains a concern since the steam side is enclosed within the plate. In other words, the only cleaning mechanism available is by chemical means. Impurities in the steam must therefore be avoided.

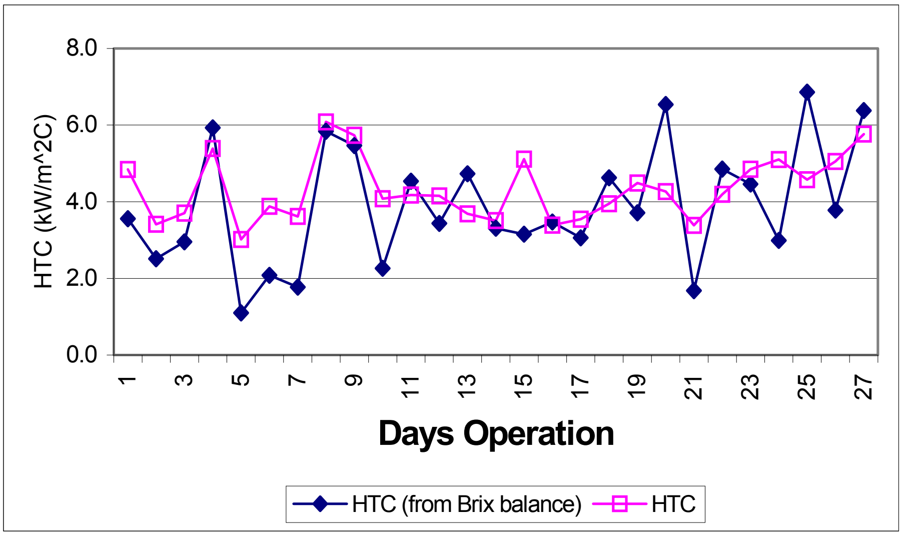

Figure 3. Heat transfer coefficients for second effect.

When the plate pack was opened for inspection at the end of the test, it was noted that some material had accumulated in the unused primary inlet port. This material was considered to have come from cleaning operations on the previous effect. The material was smaller than the hole size of the strainer (0.5 x 2 mm). This accumulation was of little concern since both channels would be used in the full-scale installation. It should, however, be noted that any dead spot in an evaporator has the potential to cause blockages and fouling.

Fourth Effect

Operating conditions

The test package was moved to the fourth and final effect. A splitter pipe was made so that both inlet ports would be used, thereby eliminating the build-up of debris that was observed in the previous effect. Typical operating conditions are shown in Table 3.

Although a chemical clean was not required for the duration of the test, it was decided that this should nonetheless be done at the end of the test. The object was to test the application of the chemical cleaning procedure described by the manufacturer.

Table 3. Typical operating conditions for fourth effect.

Brix in	43.4-65.1%
Brix out	53.0-72.8%
Pressure V3 steam	˜54.5 kPa (g)
Mass flow condensate	0.8-1.4 tons/h
Mass flow feed	4.2 tons/h
Recycle	1.4 tons/h

Results and observations
The calculated HTCs are shown in Figure 4. The plate evaporator HTC also exceeds those that would be anticipated for a shell and tube installation, which has a design value of 0.7 kW/m^2 ºC (Love *et al.*, 1999). Some degradation of the HTC can be seen in Figure 4. The fouling rate was estimated to be 0.058 kW/m^2 ºC/day.

Although some soft scale remained after the chemical clean, it was accepted that this would be improved with proper control and the correct cleaning chemical composition. The scale was soft and did not get caught in the juice passages. In the full-scale model, provision would be made to wash the sludge out through the inlet channels or the CIP port, if one was provided. In the pilot test, the sludge simply accumulated in the inlet channels.

Owing to time constraints, a second run after CIP was not possible. A visual inspection of the plates, however, showed that much of the scale had been removed. The remaining scale would probably have been removed if stricter control of the chemical concentrations had been instituted. There was no evidence of blocking of the plate passages.

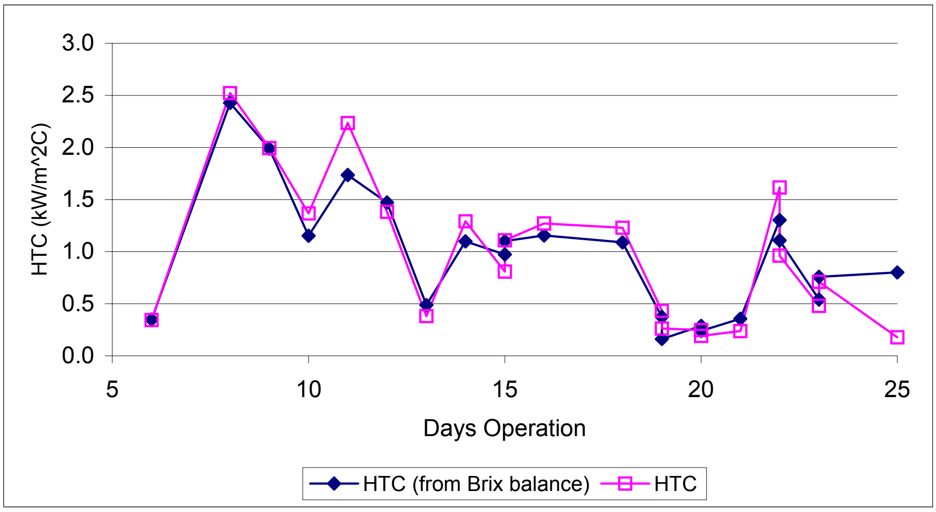

Figure 4. Heat transfer coefficients for fourth effect.

General Observations

Summary of results
A summary for the HTCs for the three tests is given in Table 4.

Table 4. Summary of average HTCs for each effect.

	First effect	Second effect	Fourth effect
HTC (brix)	2.6 kW/m^2 ºC	3.8 kW/m^2 ºC	0.95 kW/m^2 ºC
HTC (condensate)	2.5 kW/m^2 ºC	4.0 kW/m^2 ºC	0.97 kW/m^2 ºC
Brix change	5.0%	7.0%	13.6%
Previously reported (design) (Love *et al.*, 1999)	2.5 kW/m^2 ºC	2.2 kW/m^2 ºC	0.7 kW/m^2 ºC

Cleaning and control
Previous experience at Glendale (Friedrich, 1995), Ubombo Ranches (De Beer and Moult, 1998) and Hippo Valley (Walthew, 1996) sugar factories showed very clearly that a poorly designed plate evaporator installation could have disastrous results. Any dead spots or dry operation of a plate evaporator could cause abnormal fouling. Unlike applications with shell and tube technology, mechanical cleaning is not a practical option. It is therefore important that any scale that may be formed can be removed chemically and does not block the juice passages.

Quality of steam
The steam side is not accessible to any form of mechanical cleaning. It is also likely that chemical cleaning on the steam side will be difficult. It is therefore imperative that the steam must be free of entrained impurities.

Opening of the plate pack
The plate was secured with a series of large bolts. These could easily be removed, allowing the plates to be split. In previous models, it was necessary to replace the gasket if fouling occurred around the gasket. The AlfaVap 700 plates were redesigned to avoid fouling around the gasket. No deterioration of the gasket or fouling was detected for the duration of the test, indicating that the changes made to the plate profile were indeed effective. A tightening procedure was required to ensure proper seating of the gasket. Misalignment or over-tightening could cause distortion of the plate or gasket and result in leaks.

Juice distribution
One aspect of the evaporator that could not be tested was the effectiveness of the juice distribution arrangement within the plate packs. The design is such that the juice entering the evaporator is subdivided between sets of plates, or cassettes, to ensure that an even distribution of juice along the entire evaporator is achieved. Only a full-scale test will show whether the design has achieved this objective.

Conclusions

Performance
The HTCs measured on the AlfaVap 700 plate evaporator for first, second and fourth effect configurations compared favourably with, or exceeded, those that would be used in the design of equivalent shell and tube equipment. It should be noted, however, that pilot plants generally produce heat transfer coefficients that are 10-20% higher than those that can be achieved in a full-scale factory.

The full heat transfer potential of the plate evaporator was only demonstrated in the second effect where the heat transfer coefficient was measurably higher than the equivalent shell and tube evaporator. In the first and fourth effects, difficulties were experienced in providing the flows necessary to achieve the expected heat transfer coefficients.

Product side fouling
Only a thin layer of soft scale formed. This scale was easily removed and no fouling problem was identified for the conditions under which the test was run.

Steam side fouling
Should steam side fouling occur, problems might be experienced in implementing a cleaning scheme.

Suitability and application
A plate heat exchanger system requires a plate pack and a separator. If existing vessels can be used as separators, the plate heat evaporator would be ideal for boosting capacity.

To maintain the correct liquid levels and wetting rates, it is necessary to use pumps for forced circulation. Shell and tube designs have the advantage that natural convection can be used.

To avoid problems from carry-over in the steam, it is probably better to install the plate evaporator as part of the first effect.

If the AlfaVap 700 were to be used as the primary evaporator in a new installation, special care would be needed to ensure complete separation of the juice from the vapour. This means that provision for separators would have to be made adding both volume and cost to the installation.

The control system must protect the plates from running dry.

Acknowledgements

The authors would like to thank the management of Malelane sugar mill for allowing this work to be completed, and the staff for their assistance. Gratitude is also expressed to Carl van Maanen, Nigel Jagenath and Henrik Kockum of Alfa Laval for their technical and practical inputs.

REFERENCES

De Beer TH and Moult JM (1998). Experiences with plate evaporators at Ubombo Ranches in Swaziland. *Proc S Afr Sug Technol Ass* 72: 228-233.

Friedrich C (1995). Glendale climbing film plate evaporator. Technical Note 46/95. Sugar Milling Research Institute, University of Natal, Durban. South Africa.

Kampen WH, Monge A and Englio J (1999). Experience with a (pilot) rising film plate evaporator and new mist eliminator in Louisiana. *int Sug J* 101(1210): 523-526.

Love DJ, Meadows DM and Hoekstra RG (1999). Robust design of an evaporator station as applied to Xinavane. *Proc S Afr Sug Technol Ass* 73: 211-218.

Nilsson I (1994). Industrial plate evaporators. *Proc S Afr Sug Technol Ass* 68: 125-127.

Reid MJ (1995). A brief appraisal of the plate evaporator. Technical Note 25/95. Sugar Milling Research Institute, University of Natal, Durban. South Africa.

Reid MJ and Rein PW (1983). Steam balance for the new Felixton II mill. *Proc S Afr Sug Technol Ass* 57: 85-91.

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.

Walthew DC (1996). An examination of the plate evaporators at UR. Technical Note 22/96. Sugar Milling Research Institute, University of Natal, Durban. South Africa.

Walthew DC (1997). An assessment of the performance of mixed juice plate heaters at HV. Technical Note 22/97. Sugar Milling Research Institute, University of Natal, Durban. South Africa.

Walthew DC, Wienese A, Squires R and Friedrich C (1996). Preliminary assessment of a rising film plate evaporator. *Proc S Afr Sug Technol Ass* 70: 225-230.

APPENDIX A

Calculation of Heat Transfer Coefficients

The basic form for the heat transfer relationship is:

$$Q = k_{app} A \Delta T_{app}$$

where

Q	=	heat transferred
k_{app}	=	apparent heat transfer coefficient
A	=	area
ΔT_{app}	=	apparent temperature change

The temperature difference used was the difference between the temperature of the incoming steam (calculated from pressure PT200 in Figure 1) and the outgoing juice/vapour mixture temperature (TT102 in Figure 1).

The heat transferred, Q, was calculated in two ways:

- A heat balance using the condensate mass flow yields

$$Q = \rho_{cond} V_{cond} (h_s - h_c)$$

where

ρ_{cond}	=	density of condensate
V_{cond}	=	volumetric flow rate
h_s	=	enthalpy of steam
h_c	=	enthalpy of condensate

- An energy balance from brix yields

$$Q = \rho_{feed} V_{feed} \left(\frac{Bx_{feed}}{Bx_{out}} h_{out} + \left(1 - \frac{Bx_{feed}}{Bx_{out}}\right) h_v - h_{feed}\right)$$

where

ρ_{feed}	=	density of juice in
V_{feed}	=	volumetric flow – rate juice in
Bx_{feed}	=	brix of juice in
Bx_{out}	=	brix of juice out
h_{feed}	=	enthalpy of juice in
h_{out}	=	enthalpy of juice out
h_v	=	enthalpy of vapour

The enthalpies were calculated using the relationships:

- steam

$$h_s = 2500 / P_s^{0.0195} - 0.26 P_s + 4.187 T_s$$

where

h_s	=	enthalpy of steam or vapour (kJ/kg)
P_s	=	pressure of steam (kPa)
T_s	=	temperature of steam (ºC)

- condensate

$$h_c = 4.187 T_c$$

where

h_s	=	enthalpy of steam or condensate (kJ/kg)
T_c	=	temperature of condensate (ºC)

- juice

$$h_j = T_j (1 - 0.006 Bx) * 4.187$$

where

h_j	=	enthalpy of juice (kJ/kg)
T_j	=	temperature of juice (ºC)
Bx	=	brix of juice (%)