FACTORS AFFECTING THE PERFORMANCE OF LONG TUBE CLIMBING FILM EVAPORATORS

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Abstract

A pilot evaporator was used to investigate some of the factors which could influence the performance of long tube climbing film evaporators. The overall performance of an evaporator will be the result of the immediate operating conditions in the short term, as well as the rate of fouling. The effect of selected operating conditions on the performance of a clean evaporator working under non-fouling conditions was considered using a factorial design. The fouling behaviour was examined with respect to feedrate. Increasing the feedrate was found to improve the heat transfer coefficient in both the short and long terms. The fouling resistance, measured under controlled conditions, was found to be reduced at higher feedrates.

Keywords: Evaporation; Heat transfer coefficient; Fouling

Introduction

In many of the local sugar mills the evaporator station is considered to be the operation which limits throughput. Since long tube climbing film evaporators (Kestners) are common in early effects, and are considered to be performing less than optimally, such evaporators have become a focus for research in the sugar industry. To this end a pilot evaporator, containing three, seven meter long, 50 mm diameter tubes, has been constructed at Felixton mill. This plant can be operated under varied controlled conditions and the performance can be monitored through measurement of the overall heat transfer coefficient (HTC). Details regarding the features, operation, and methods of treating the data from the pilot plant have been reported elsewhere (Walthew *et al.,* 1995a and b). For convenience the procedure used to calculate the HTC is summarised in Appendix 1.

While there are many changes which can be made to sugar mill evaporator trains to improve performance, this paper is primarily concerned with some of the factors which can be altered relatively easily in the factory. A factorial design was used to examine the influence of selected factors on the HTC, using clean tubes, operating in a non-fouling environment. The effect of feedrate on evaporator performance was then examined in more detail.

A factorial investigation into performance

The objectives of this set of experiments were to determine the relative importance of selected factors on HTC and to establish any interaction between the factors. The details regarding the procedures and methods of analysis for factorial design are beyond the scope of this report, but the approach taken is based on the report by Lionnet *et al.* (1977). A detailed description of these experiments is contained in a separate report (Walthew *et al.*, 1996) and only the main findings are reported in this paper.

Since the best measurement of evaporator performance is through calculation of the HTC, this was selected as the dependent variable or 'result'. The value of the HTC was most reliably calculated by measuring the flowrate of the calandria condensate, this being a good measure of the heat transferring across the evaporator tube walls. The independent variables (factors) which were selected for study were:

- The average temperature difference between the steam and the juice, or 'ΔT'
- The feedrate
- The feed temperature
- Recycle, which was either on (open) or off (closed)
- Brix of the feed juice (BX)

The selection of the independent variables and the values for each level were based on prevailing conditions of operation for first effect evaporators in the industry. An exception to this was the 'high' feed juice temperature which, because of technical difficulties, could not be maintained above 110°C. Since the vapour pressure may have an influence on the HTC it was kept constant in all cases and the 'ΔT' was varied by changing the steam pressure. All these experiments were carried out using relatively new, clean tubes. The sugar solution used was made using very high pol sugar and thus no fouling occurred during the experimental runs. Since fouling has an important effect on evaporator performance the measured HTCs are higher than would be expected in the industry. Each of the factors was investigated at two levels, i.e. high and low (except for the recycle which could only be on or off). The design is summarised in Table 1 which is self explanatory. The codes and variable names are those used in the results.

Factorial results and discussion of main effects and interactions

The experimental data were analysed by performing an analysis of variance using a 95% confidence interval and interactions greater than two were ignored. The analysis indicated the following:

- The HTC was significantly increased at higher levels of ΔT, feedrate and brix. The increase in HTC with increasing feedrate and ΔT can be explained in terms of conventional theory in that turbulence is promoted, reducing resistance to heat transfer by preventing the formation of a laminar liquid layer. However, an increase in HTC at higher brix levels is unexpected since higher brix levels are associated with higher viscosities. The brix values used are still relatively low and the HTC will certainly drop at higher brix values.
- Significant interaction was found to occur between the feed temperature and the recycle, shown in Figure 1, and indicates that at high feed temperatures, having the recycle open, greatly improves the HTC. This suggests that at the higher temperatures without recycle, 'dryout' is occurring, i.e. the liquid flowrate is not sufficient to 'wet' the entire length of the tube. When it is considered that feed temperature used at the 'high' level is still about 5°C less than

the typical clear juice feed temperature used in the industry, it is highly likely that dryout is occurring in factory Kestner evaporators without a recycle.

Table 1

Experimental design

	Description	Name	Unit	Level	Code	Value
Dependent variable	Overall heat transfer coefficientl	HTC	kW/m² °C	-	-	-
Independent variables	'ΔT'	DT	°C	High	DTH	7,5
				Low	DTL	4
	Feedrate	FR	kg/min	High	FH	4,5
				Low	FL	2,5
	Feed juice temperature	FT°C	°C	High	FTH	110
				Low	FTL	102
	Recycle	RC	-	On	RON	open
				Off	ROF	closed
	Brix	BX	%	High	BH	13
				Low	BL	8

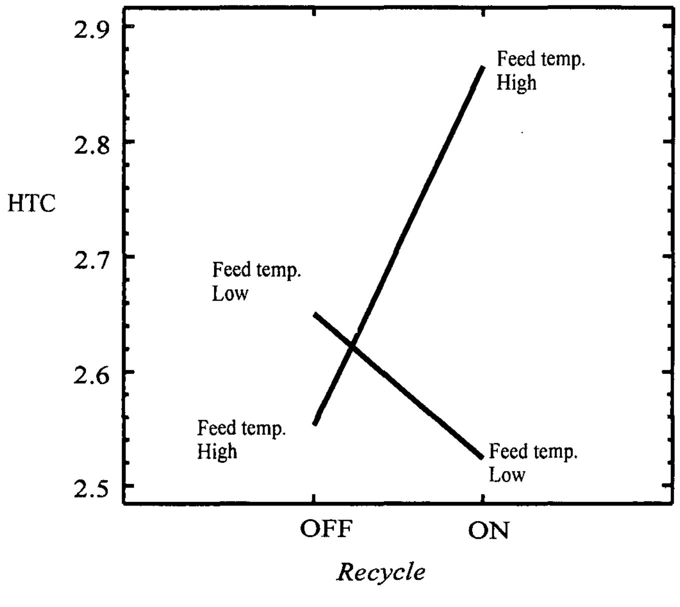

FIGURE 1: Interaction between feedrate and recycle.

Rather than providing a definitive answer to the problems of seeking the optimum operating conditions, the factorial results provide some direction for further investigation. Of all factors which could significantly improve performance, feedrate was found to be worthy of further examination since it can be relatively easily altered, with minor disruption to the evaporator station, either by increasing the feedrate or through the use of recycle. Consequently further tests were carried out with the specific intention of studying the relationship between feedrate and performance.

An examination of the effect of feedrate on performance

Controlled testing

The factorial experimentation examined the feedrate effect at two levels only. To extend this work a series of tests was carried out in which the feedrate was varied while all other conditions were kept constant. In these runs four tests were performed in which the evaporator was operated as a first effect (feed brix 10-13%), and a second effect (feed brix 16-20%), each with clean and fouled tubes, using factory juices. The results are shown graphically in Figure 2. This shows that the HTC is quite significantly improved by increasing the feedrate and, although a limit is reached, there is no decline in the HTC even at the highest feedrate possible (limited by the feed pump). The highest feedrate used was twice the typical operating feedrate for the Felixton evaporators. Figure 2 also shows that the difference between first and second effect operation is swamped by the effect of fouling. As expected, the HTC is reduced by the presence of scale and the shapes of the curves are similar. These results confirm that an improvement in the short term performance of Kestner evaporators could result from increased feedrate.

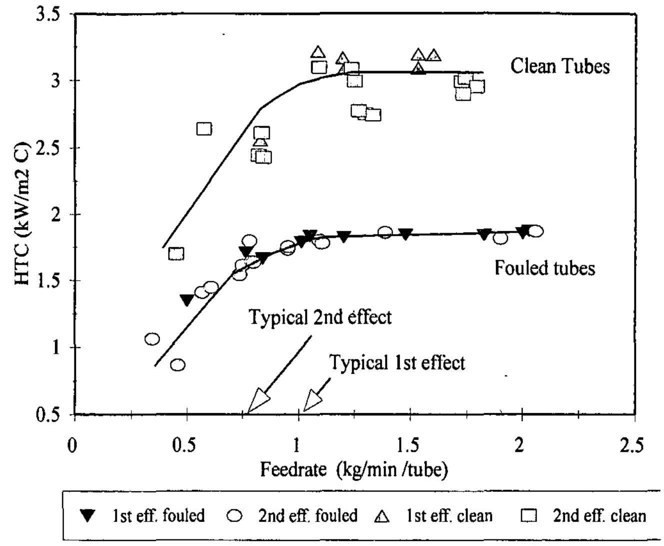

FIGURE 2: The effect of flowrate on the HTC for clean and fouled tubes, when the pilot plant was run as first and second effects.

Method of measuring the fouling

Theoretical considerations suggest that fouling is generally reduced at higher flowrates (Bott, 1995) and therefore increasing the feedrates could reduce both the rate and extent of evaporator fouling, offering long term benefits. The effect of fouling on the HTC was measured in terms of the fouling resistance which was calculated from the change in the HTC over time. The HTC measured after time t (U_t) is related to the fouling resistance (R_f) and the HTC when the evaporator surface is clean (U_0) by the relationship:

$$1/U_t = 1/U_0 - R_f$$

Since the fouling resistance is related to the thermal conductivity of scale (k) and the scale thickness (x) by:

$$R_f = x/k$$

the fouling resistance gives a direct indication of the amount of scale deposited on the evaporator surface. The simple fouling model of Kern and Seaton (Bott, 1995) gives the fouling resistance (R_f) after time t by the following equation:

$$R_f = R_\infty - R_\infty \exp(\beta t^2)$$

where R_∞ is the asymptotic value of the fouling resistance and â is a constant. By correcting t to account for an induction time, the experimental results could be fitted to the model so that the value of R_∞ and β could be determined.

The effect of feedrate on fouling rates

The pilot plant was run at different feedrates to determine the change in the HTCs (and hence the fouling resistance) over time. In all cases the feed juice used was sourced from the outlet of the first effect evaporators and the conditions of operation of all runs are summarised in Table 2. The results of these tests are shown graphically in Figures 3 and 4. To simplify the presentation of the results, only the curves resulting from a best fit of the fouling model to the experimental data are shown. Figure 3 gives the change in the calculated fouling resistance value over time and indicates an increase in the fouling resistance at lower feedrates. The magnitude of the change in the calculated asymptotic fouling resistance with feedrate is more clearly seen in Figure 4 and shows the extent to which fouling is reduced at higher feedrates. For comparison, the values for fouling resistances calculated using data from various sources are shown in Table 3 (Walthew, 1993).

Table 2

Summary of the conditions of operation used to examine the effect of flowratè on the HTC for clean and fouled tubes, when the pilot plant was run as first and second effects

Tube condition	Effect simulated	Feed	Average			
			Feed brix %	Product brix %	ΔT (°C)	Feed juice temperature (°C)
Clean	1st	Clear juice	11	20	6,5	108
	2nd	1st effect juice	16	33	7,2	106
Fouled	1st	Clear juice	12	20	8,2	106
	2nd	1st effect juice	18	36	7,8	105

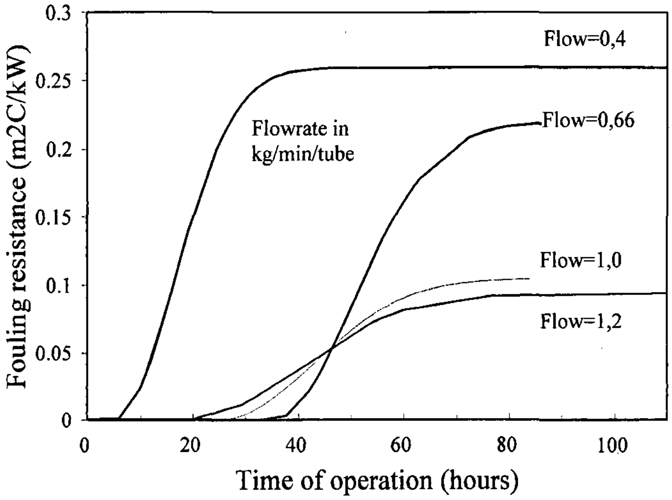

FIGURE 3: The effect of feedrate on the fouling resistance. Only the curve obtained from a best fit to the experimental data is shown in each case.

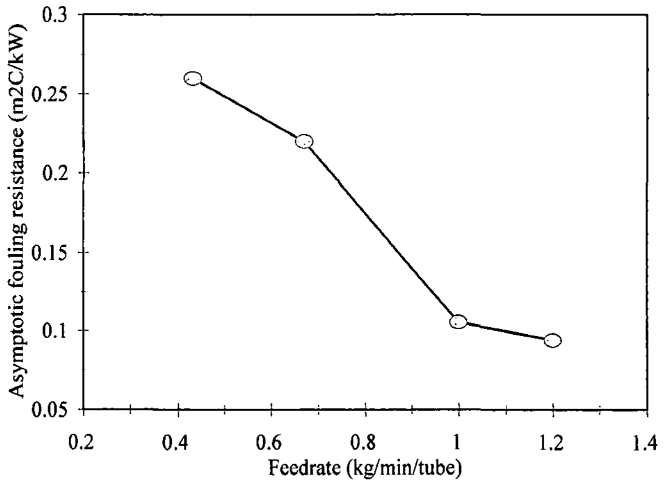

FIGURE 4: The magnitude of the change in the asymptotic fouling resistance with feedrate.

Table 3

Fouling resistance values calculated for various evaporators

Mill	Evaporator type	Calculated value of the fouling resistance (m^2 °C / kW)	Reference
SZ	1st effect Kestner	2,0	Patel (1993)
PG	1st effect Kestner	0,4	Rousseau *et al.* (1995)
PG	1st effect Falling film	0,3	Rousseau *et al.* (1995)
GD/Australian mill	2nd effect rising film	0,1	Walthew et al. (1996)
	Plate evaporator		De Viana *et al.* (1993)
FX pilot plant	2nd effect simulation	0,1-0,3	This work

Discussion

The poor pilot plant evaporator performance at low flowrates can be explained in terms of simple mass balance considerations for an 'ideal' evaporator. Assuming that the evaporator surface area is fixed, limiting the flowrate will limit the quantity of available water to evaporate. If it is further assumed that the feed brix is fixed at 16% and the outlet brix from the 'ideal' evaporator cannot exceed 60%, then the best possible HTC can be calculated for various ÄT values between 5 and 10°C. The results of such a calculation are shown graphically in Figure 5 and demonstrate that where flowrates are low, ÄT is large and the feed brix is relatively high, then the poor HTC values obtained experimentally are not unexpected.

Conclusions

This work indicates that an increase in feedrate through climbing film evaporators should improve evaporator performance both in terms of an immediate improvement in the HTC, and in the longer term by reducing the rate at which the HTC is reduced with time due to fouling. While it is clear that the feedrate cannot be increased without limit, the experimental results suggest that increasing the feedrate substantially does not appear to carry the risk of a reduced HTC due to 'flooding'. Further work is now required to consider the implications of significantly higher flowrates, the maximum flowrates possible, and to consider methods of implementing these findings.

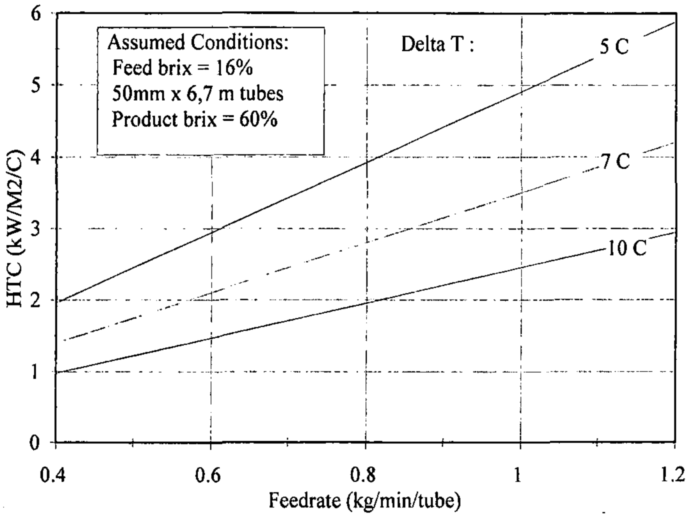

FIGURE 5: Theoretical maximum HTC values possible for a feed solution of 16% at different ΔT values and feedrates.

APPENDIX 1

CALCULATION OF THE HTC

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

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

where:

HTC = apparent heat transfer coefficient [kW/(m^2*K)]

A = Surface area (m^2)

Q = Rate of heat energy transfer from latent heat (Calandria condensate flowrate x latent heat of vapour) (kW)

dT = Ts – Tj = Temperature difference across the heat transfer surface (°C)

Ts = steamside temperature (°C)

Tj, = juice temperature out (°C)

The juice temperature was the average calculated inlet and outlet temperatures, which were determined by adding the saturated steam temperature at the measured vapour pressure to the boiling point evaluation at the relevant brix. The hydrostatic head was not taken into account. The formulas used to calculate the properties needed to obtain the HTC from the measured data are those recommended by Peacock (1995). Methods of calculation and their implications are given in more detail elsewhere (Walthew, 1994; Smith *et al.*, 1981)

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Table 4

Some calculated parameters for various first effect evaporators in the industry

Mill	Capacity tch	Surface area m^3	Tube 3			Average MJ flow t/h	Juice velocity cm/s	Wetting rate l/cm circumference	Flowrate kg/min/tub
			Length mm	Diameter mm	Number				
ML	375	3905	4665	38	7009	278	0,97	3,32	0,66
KM	225	3800	7280	51	3257	216	0,90	4,15	1,11
PG	200	3720	7000	51	3316	222	0,91	4,17	1,11
FX	600	11000	7270	51	10082	600	0,81	3,72	0,99
AK	385	5860	6680	51	5473	450	1,12	5,13	1,37
GD	90	455	1845	51	1539	109	0,96	4,41	1,18
DL	300	4650	6700	51	4330	341	1,07	4,91	1,31
GH	300	5580	6405	51	5435	303	0,76	3,48	0,93
NB	300	5890	2290/7050	51	10345	308	0,40	1,86	0,50
UC	150	2235	5010	41	3462	155	0,94	3,48	0,75
MS 1	520	4860	5334	38	7629	285	0,92	3,13	0,62
MS 2	520	3110	6630	51	2927	183	0,85	3,90	1,04
SZ	450	9920	7000	51	8841	520	0,80	3,67	0,98
UK	230	3070	7000/2300	51	4940	299	0,82	3,78	1,01
FX pilot plant low fouling trials (2nd effect)				51	3	0,21	0,94	4,33	1,16
FX pilot plant high fouling trials (2nd effect)				51	3	0,07	0,32	1,46	0,39