REFEREED PAPER

RECIRCULATION RATE FOR ROBERT EVAPORATORS

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Abstract

Research has shown that a higher fluid velocity, as a result of increased recirculation, results in improved Robert evaporator performance. Although no conclusive correlation for the optimum recirculation rate can be found in literature, extensive experimental data was made available. With the aid of a digitising program, data was extracted from existing graphs and was mathematically manipulated to yield a number of correlations. The first set of correlations allow the minimum recirculation rate and liquid level to be predicted for juice of up to 65 brix, corresponding to various temperature driving forces and the optimum heat transfer coefficient. The prediction of the juice velocity as a function of temperature driving force allows a second correlation between the Reynold number and the Grashof number to be developed, presenting the results in terms of dimensionless numbers which can be easily interpreted in terms of heat transfer theory. The correlations developed will assist in the design of semi-sealed down-takes to ensure adequate recirculation and a sufficient liquid level within the Robert evaporator to optimise heat transfer.

Keywords: Robert evaporator, recirculation rate, liquid level, down-take

Introduction

In an evaporator in the sugar industry, heat energy is transferred by steam condensation to the tube wall, followed by conduction through the tube material, and is then transferred primarily by convection from the tube wall to the bulk fluid. Most of the resistance to heat transfer occurs in convection to the process fluid and can be explained in terms of the thickness of the boundary layer.

When a moving fluid comes into contact with a stationary surface, a velocity boundary layer develops whereby the fluid velocity adjacent to the pipe surface is essentially zero. As a result of the temperature difference between the pipe surface and bulk fluid, a thermal boundary layer is also developed, contributing toward the resistance to heat transfer.

In a Robert evaporator, an increase in the fluid velocity reduces the thickness of both the velocity and thermal boundary layers, resulting in less resistance to heat transfer. The increase in fluid velocity is associated with an increase in the Reynold number and is achieved through increased recirculation of the juice, driven by natural convection in the tubes.

The Reynold number, shown in equation 1, is a dimensionless group often used to characterise fluid behaviour as either laminar or turbulent (Incropera and De Witt, 2002).

$$\mathrm{Re} = \frac{\rho d v}{\mu} \qquad \text{Eq 1}$$

where ρ = fluid density (kg/m^3)
d = diameter of the pipe through which the fluid flows (m)
v = fluid velocity (m/s)
μ = fluid viscosity (Pa.s).

The Nusselt number, a dimensionless group representing the ratio of convective to conductive heat transfer across the boundary layer, can be expressed in terms of the Reynold and Prandtl numbers for turbulent flow according to equation 2 (Incropera and De Witt, 2002).

$$Nu = 0.023\,\mathrm{Re}^{\frac{4}{5}}\,\mathrm{Pr}^{\frac{1}{3}} \qquad \text{Eq 2}$$

The Nusselt number is seen to be dependent on the Reynold number. However the Nusselt number is also directly proportional to the convective heat transfer coefficient (HTC), as shown in equation 3 (Incropera and De Witt, 2002).

$$Nu = \frac{h.d}{k_f} \qquad \text{Eq 3}$$

where h = convective heat transfer coefficient (W/m^2.K)
d = diameter of the pipe through which the fluid flows (m)
k_f = thermal conductivity of the fluid (W/m.K).

Based on heat transfer theory, improved recirculation in a Robert evaporator can be seen to increase the Reynold number which then increases the Nusselt number. From equation (3) it can be seen that the tube diameter and thermal conductivity of the fluid would remain unchanged, therefore implying an increase in the HTC.

The HTC in a Robert evaporator is known to be a function of juice brix and juice temperature (Peacock, 2007); however, an optimum liquid level corresponding to a maximum HTC is known to exist and is associated with the point at which the tubes are fully wetted (Watson, 1986). The importance of the liquid level to achieve optimum heat transfer has been widely reported (Guo *et al*., 1983; Peacock, 2007; Broadfoot and Dunn, 2007) as well as the importance of juice velocity in the form of recirculation (Guo *et al*., 1983; Bosnjak, 1969; Rein, 2007). However, no conclusive equations exist for the design of a semi-sealed down-take with particular reference to the size and positioning of the off-take cone. The aim of this paper is thus to develop a correlation allowing the calculation of the minimum recirculation rate and liquid level in a Robert evaporator.

Semi sealed down-take design

The semi-sealed down-take design, as shown in Figure 1, allows optimum heat transfer to be achieved (Rein, 2007), where the diameter of the down-take itself is recommended to be between one-eighth to one-quarter of the vessel diameter (Hugot,1972).

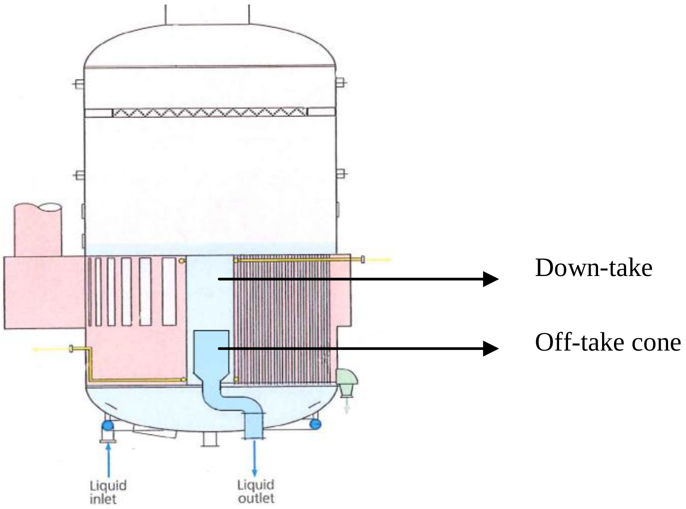

Figure 1. Semi-sealed down-take design (adapted from Rein, 2007).

Careful positioning of the off-take cone within the down-take enables a minimum liquid level to be maintained, and thus ensures the constant wetting of the tubes.

The open area within the down-take allows recirculation to occur, while the sealed off-take cone and outlet pipe capture the exiting juice and thus eliminate the danger of short-circuiting of juice from the feed to the outlet pipe.

Optimum liquid level

Flow regimes in a vertical boiling tube

The various flow regimes in a vertical tube of boiling liquid can be seen in Figure 2. The single phase liquid region is associated with the lowest rate of heat transfer, which then increases upon bubble formation, where bubbly flow is seen to transition to slug flow. In the annular regions E and F, heat is convected through the liquid film and represents the regime with the highest rate of heat transfer. The dry-out point, shown in Figure 2, is associated with the point at which the liquid film ceases to fully cover the tube surface. As a result, the surface area above the dry-out point contributes very little to the heat transfer process and results in a rapid reduction of the HTC and an increased rate of tube fouling.

As the liquid level in a tube is increased, the liquid deficient region, region G, is reduced resulting in greater heat transfer through the liquid film and a rapid increase in the HTC, as seen in Figure 3. The maximum HTC, associated with the optimum liquid level, can be achieved with a fully wetted tube with no region deficient of liquid, and with the annular boiling regions extending to the top of the tube.

As the liquid level is increased above the optimum point, the higher hydrostatic level results in a greater boiling point elevation and suppresses the onset of bubble formation. This causes a greater region of single phase flow, represented by region A, resulting in the gradual reduction of the HTC, as seen in Figure 3.

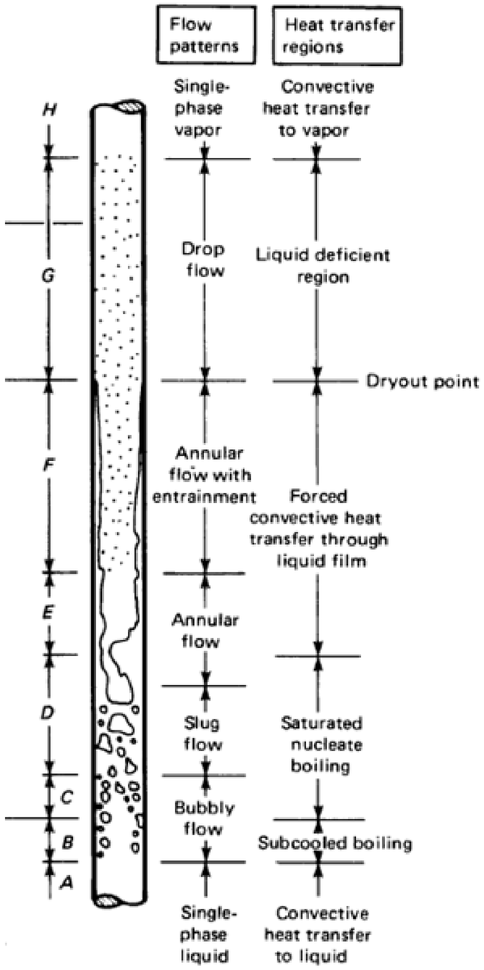

Figure 2. Natural boiling in a vertical tube (Lienhard and Lienhard, 2008).

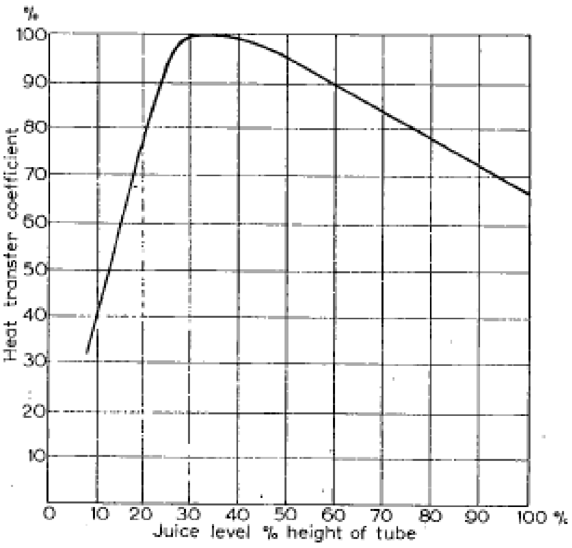

Figure 3. The effect of liquid level on the heat transfer coefficient (Hugot, 1972).

Recommended liquid level

Hugot (1972) reports the optimum liquid level within an evaporator tube to be one third of the tube height and further recommends a trend of decreasing liquid level with increased juice concentration as shown in Table 1.

Table 1. Summary of liquid levels recommended by Hugot (1972).

Optimum liquid level as % of tube height	Evaporator effect
40	1st effect
25	2nd effect
20	3rd and 4th effects

Broadfoot and Dunn (2007), however, reported a trend of increasing liquid level with increased juice brix. However, the optimum liquid level has been shown to be ultimately dependent on the temperature driving force between the steam and juice (Guo *et al.*, 1983) where lower liquid levels are optimal at higher temperature driving forces (Peacock, 2007).

Recirculation

Recirculation in a Kestner evaporator

Work by Walthew and Whitelaw (1996) illustrated the effect of recirculation rate on the HTC for first and second effect Kestner evaporators, as shown in Figure 4.

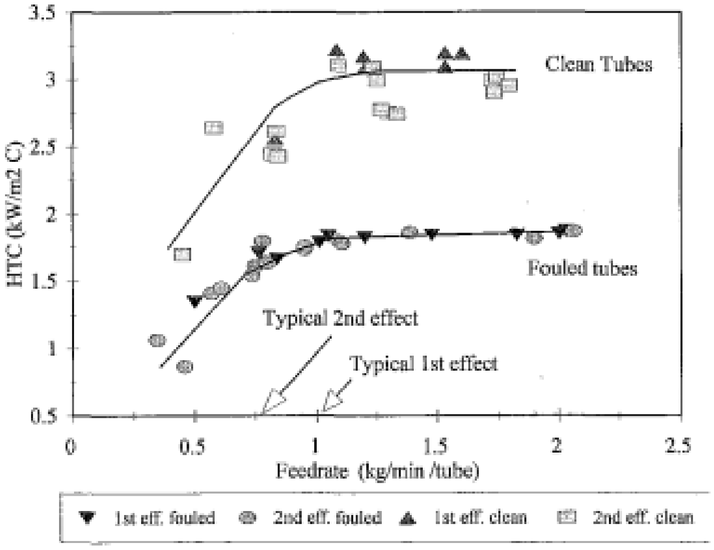

Figure 4. The effect of flow rate on the heat transfer coefficient for clean and fouled evaporator tubes (Walthew and Whitelaw, 1996).

The recirculation rate at which the maximum HTC is achieved in Kestners corresponds to a recirculation rate of approximately 1.2 kg/min/tube. In the absence of better data, it has therefore been current practice to design the off-take cone diameter for Robert evaporators for a minimum recirculation rate of 1.2 kg/min/tube.

Recirculation in a falling film evaporator

Work carried out on a falling film evaporator recommends a juice flow rate of approximately 8 to 16 L/cm/hr (Morgenroth *et al*., 1995). Assuming a density of 1000 kg/m^3, the optimum flow rate for falling film evaporators equates to a recirculation rate of between 1.05 to 2.1 kg/min/tube. Alternatively, the recirculation rate can be expressed as between 0.017 to 0.035 kg/s. While these results allow the recirculation rate to be placed in context for a Kestner or falling film evaporator, work done by Guo *et al*. (1983) can be regarded as most pertinent to the Robert evaporator operation.

Analysis of published recirculation rate and liquid level data for application to a robert evaporator

Experiments carried out by Guo *et al*. (1983) with water at 100°C in a triple tube evaporator (44 mm in outer diameter and 1.9 m in length) illustrate results for the effect of liquid level on the HTC and recirculation rate. The raw data from Guo *et al*. (1983) was obtained by digitisation of the original graphs using Image J to produce Figures 5 and 6. Image J is a free image analysis software package available on the internet[1]. The raw data has been summarised in the form of equations in Appendix 1.

Whilst this data was produced for water at 100°C, it was reported that similar trends were evident for varying liquid level, temperature driving force and boiling point for sugar solutions up to 65% brix.

It was also noted that the optimum liquid height at which the maximum heat transfer coefficient was obtained did not vary with brix, but rather with the temperature driving force which possessed the greatest influence (Guo *et al*., 1983).

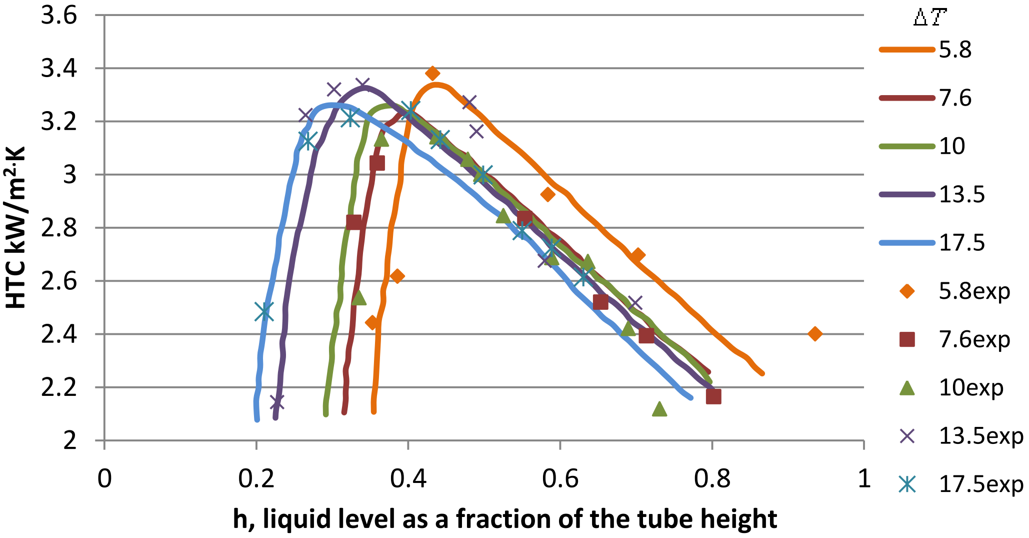

Figure 5. Digitised graph of heat transfer coefficient (HTC) vs liquid height for water at 100°C (adapted from Guo *et al*., 1983)

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[1] http://imagej.nih.gov/ij/

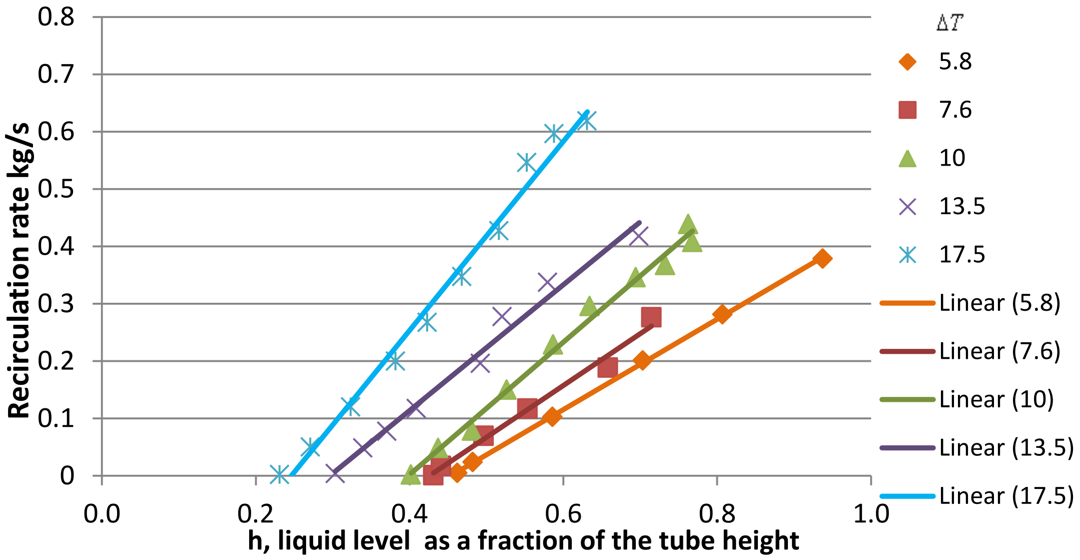

Figure 6. Digitised graph of recirculation rate vs. liquid level for water at 100°C (adapted from Guo *et al*., 1983).

Referring to Figure 5, it can be seen that, at low levels, the rate at which the HTC rises with increased liquid level is greater than the rate at which the HTC falls at high levels. As a result, different equations were used to characterise this behaviour, and these can be seen in Appendix 1, Tables 4 and 5.

The shape of the heat transfer coefficient curve with varying liquid level shows that it is preferable to err on the high side rather than the low side, as the heat transfer consequences are less severe. In addition, fouling considerations also favour higher operating levels. The maximum HTC was also seen to coincide with the onset of recirculation, as shown in Figure 6.

The data obtained from the digitised graphs was then mathematically manipulated to obtain a trend of the minimum liquid height and recirculation rate as a function of temperature driving force.

Mathematical manipulation of the raw data

Optimum liquid level

Based on the equations of the graphs from Figure 5 (Table 4 of Appendix 1), the liquid height corresponding to the maximum heat transfer coefficient was calculated for each temperature difference, and the results can be summarised in table 2.

Table 2. Summary of the liquid level corresponding to the maximum heat transfer coefficient (HTC) in Figure 3.

ΔT	Liquid height fraction	Maximum HTC kW/m^2.K
17.5	0.30	3.31
13.5	0.33	3.36
10.0	0.37	3.31
7.6	0.39	3.29
5.8	0.44	3.40

An equation expressing the optimum liquid height as a function of temperature driving force was reported by Guo *et al*. (1983) and can be seen in equation 4.

$$h_{opt} = 0.22 + 0.45\exp\left(\frac{-\Delta T}{8}\right) \qquad \text{Eq 4}$$

where h_{opt} = is the optimum liquid level to achieve maximum heat transfer, expressed as a fraction of the tube height

ΔT = is the temperature difference in °C between the heating medium and outlet juice.

Whilst an optimum liquid level exists for heat transfer, as seen in Figure 5, a minimum liquid level is also required for the onset of recirculation, as seen in Figure 6. An equation for the minimum liquid level should therefore satisfy both the heat transfer requirements and the recirculation requirements in order to ensure optimum performance.

Based on the equations of the graphs from Figure 6 (Table 6 of Appendix 1), the minimum liquid height corresponding to the onset of recirculation was calculated and compared to the liquid height for the maximum HTC, and the larger of the two values was recorded. This value reflects the lowest liquid level at which a Robert evaporator should be operated.

Comparing the minimum liquid level required to initiate recirculation with the equation developed by Guo *et al*. (1983) to achieve optimum heat transfer, this equation appeared to under-estimate the required liquid height, resulting in the condition for recirculation not being met. Further manipulation of the data led to the development of equation 5, which allows the prediction of the minimum liquid height in a tube, therefore ensuring good heat transfer and recirculation (Figure 7).

$$h_{\min imum} = -0.0149.\Delta T + 0.5816 \qquad \text{Eq 5}$$

where $h_{minimum}$ = minimum liquid level as a fraction of the total tube height

ΔT = temperature driving force between the steam and juice.

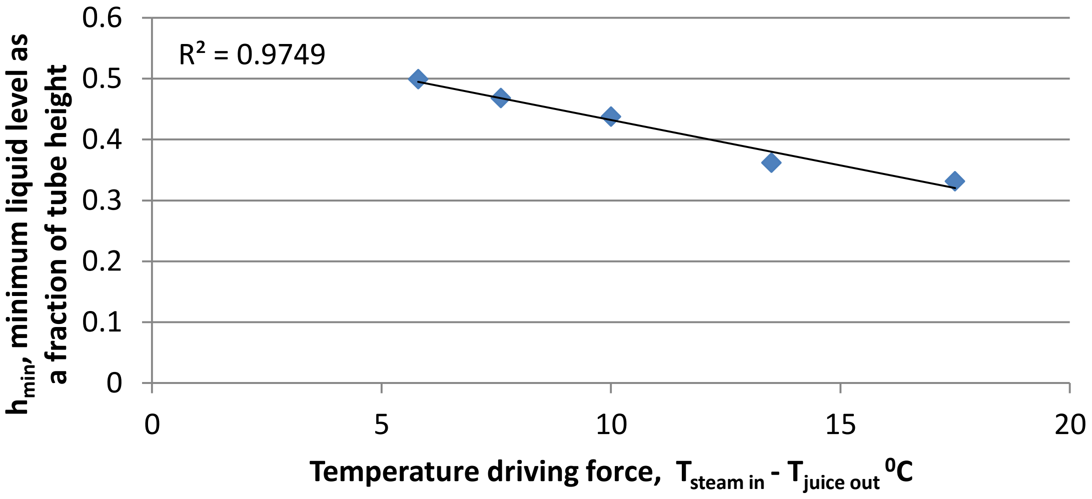

Figure 7. Minimum liquid level vs temperature driving force.

Minimum recirculation rate

The minimum liquid level calculated in equation 5 can be used together with the data from Figure 6 (shown in Table 6 of Appendix 1) to calculate the minimum recirculation rate for each temperature driving force. Plotting these two values (as shown in Figure 8) allows the recirculation rate to be predicted according to equation 6.

$$R \;\; (\mathrm{Re}circulation\,rate) = 0.008123(\Delta T)^2 - 0.0246\Delta T + 0.4744 \qquad \text{Eq 6}$$

where R = recirculation rate in kg/min/tube
ΔT = temperature difference between the heating medium and outlet juice in °C.

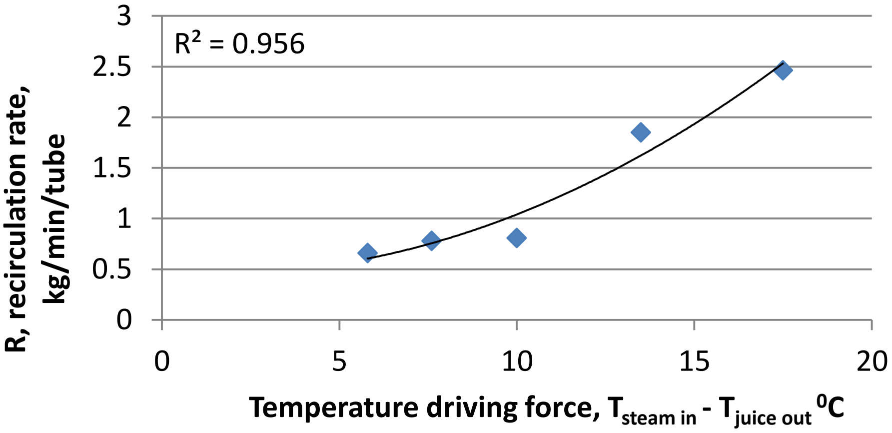

Figure 8. Minimum recirculation rate as a function of temperature driving force.

The recirculation rate represented in equation 6 corresponds to a tube with an outer diameter of 44 mm, as used in the experiments carried out by Guo *et al*. (1983). In order to use this relationship for tubes of a different diameter, the recirculation rate was converted to a wetting rate in kg/s/m of wetted perimeter, as shown in Figure 9.

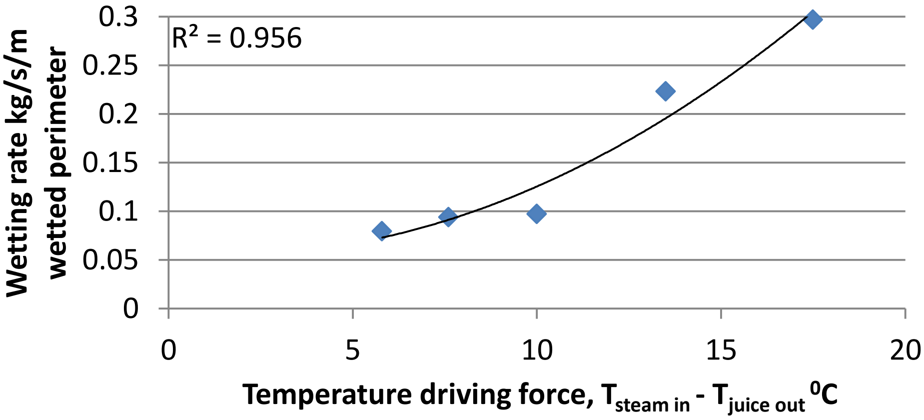

Figure 9. Minimum wetting rate as a function of the temperature driving force.

For tubes of a larger diameter, the wetting rate expressed in equation 7 can be multiplied by the tube perimeter to yield the wetting rate per tube.

$$WR \quad (Wetting\ Rate) = 0.001053(\Delta T)^2 - 0.003188\Delta T + 0.06148 \qquad \text{Eq 7}$$

where WR = wetting rate in kg/s/m
ΔT = temperature difference between the heating medium and outlet juice in °C.

Although the wetting rate expressed in equation (7) above is transferrable between evaporator tubes of various diameters, heat transfer theory may provide a more sound correlation which can be used as the benchmark for the optimum wetting rate.

Heat transfer theory and dimensional analysis

Dimensional analysis was employed to establish the relationship between the temperature driving force and juice velocity in terms of dimensionless numbers. The Reynold number and Grashof number (the ratio of buoyancy to viscous forces acting on a fluid arising during natural convection) were found to be the dimensionless groups that best represented the heat transfer and fluid dynamics involved (Incropera and De Witt, 2002).

The development of the Reynold/Grashof correlation required the following input data (Tables 7 and 8 of Appendix 2):

- Juice inlet brix
- Steam temperature T_s
- Temperature driving force or $(T_s\text{-}T)$.

The wetting rate for each tube was calculated from equation 7 and multiplied by the wetted perimeter of the tube to yield a recirculation rate in kg/min/tube. This was then used to calculate the fluid velocity and the Reynold number according to equation 1.

The temperature driving force data was used in the Grashof number calculation according to equation 8 (Incropera and De Witt, 2002).

$$Gr = \frac{g.\beta.(T_s - T)d^3}{\nu^2} \qquad \text{Eq 8}$$

where g = acceleration due to gravity (or 9.8 m/s^2)
Ts = heating surface temperature (°C)
T = temperature of juice (°C)
d = tube diameter (m)
β = coefficient of thermal expansion calculated according to equation 9[2]

$$\beta = -3.53\times10^{-8}\left(\frac{1}{T}\right)^2 + 3.03\times10^{-5}\left(\frac{1}{T}\right) - 5.65\times10^{-3} \qquad \text{Eq 9}$$

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[2] http://engineeringtoolbox.com/water-thermal-properties-d_162.html

where T = juice temperature in Kelvin
ν = The kinematic viscosity (m^2/s) which can be calculated according to equation 10 by dividing the fluid viscosity μ (Pa.s) by the fluid density ρ (kg/m^3).

$$\nu = \frac{\mu}{\rho} \qquad \text{Eq 10}$$

All fluid properties used in developing the correlation were evaluated at the film temperature T_f, calculated according to equation 11, and at the tube inlet conditions.

$$T_f = \frac{T_S + T}{2} \qquad \text{Eq 11}$$

The data obtained from experiments carried out by Guo *et al*. (1983) was therefore used to develop a correlation between the Reynold and Grashof numbers.

Development of the Reynold/Grashof correlation

The liquid level and recirculation correlations developed in this study were combined with the data from Guo *et al*. (1983) (Table 7 of Appendix 2) to yield the following Reynold/ Grashof correlation for sugarcane juice with a concentration of up to 65% brix in a Robert evaporator with an R^2 value of 0.838, as seen in equation 12 and Figure 10.

$$\mathrm{Re} = 437.95 e^{\left(2.418 \times 10^{-8} . Gr\right)} \qquad \text{Eq 12}$$

A juice purity of 85% was assumed.

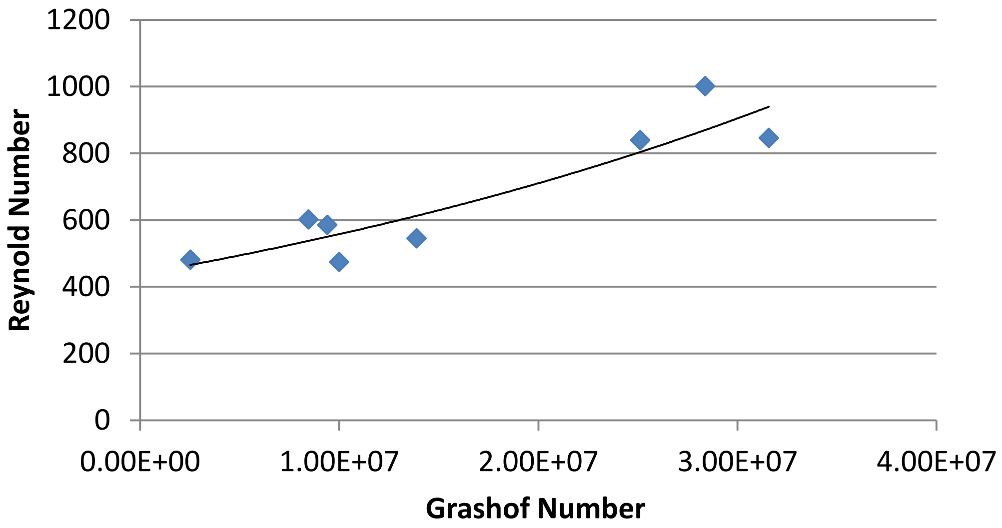

Figure 10. Reynold/Grashof correlation.

The recirculation rate, based on the data of Guo *et al*. (1983) and that of Tongaat Hulett (as seen in Appendix 2), was calculated from equation 7 and plotted against the recirculation rate calculated from the Reynold/Grashof correlation in equation 12. The Reynold/Grashof correlation was found to fit well for the data from evaporators installed in Tongaat Hulett factories, as seen in Figure 11. The correlation results using the data from Guo *et al*. (1983)

were found to fit well for a temperature driving force less than 10°C, however, for a temperature driving force higher than 10°C, the correlation was found to predict much larger recirculation rates, as illustrated by the two outlying points in Figure 11. For ease of comparison, the Reynold and Grashof numbers for Tongaat Hulett data were calculated using the same method as for the data of Guo *et al*. (1983) and were plotted on Figure 11 for tubes of varying diameter. The results from the correlation predicted values slightly higher than that of Guo *et al*. (1983) with the tubes of larger diameter (50.8 mm) requiring a greater flow rate.

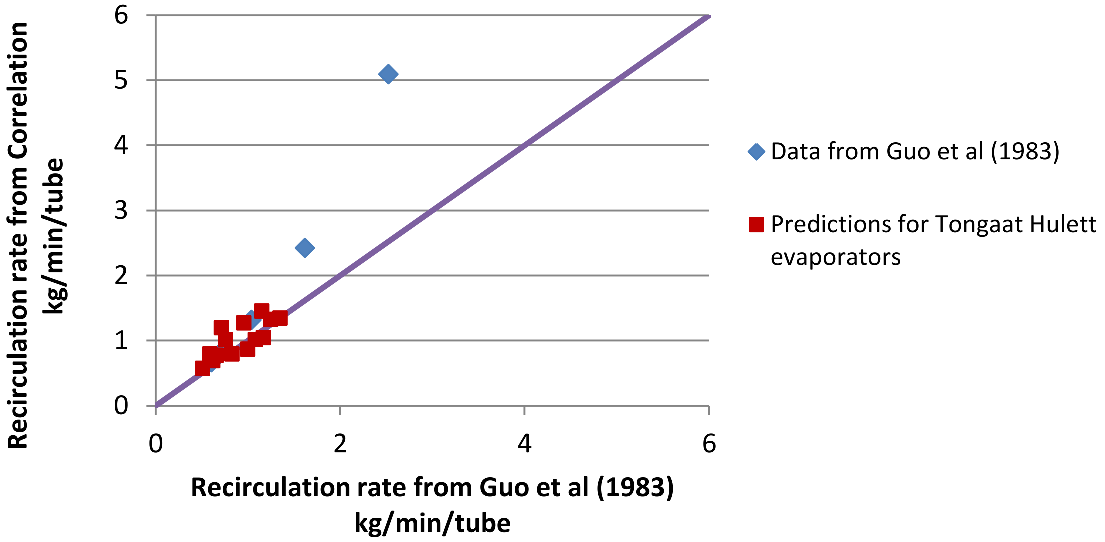

Figure 11. Graph illustrating the fit between the recirculation rate obtained from Guo *et al.* (1983) vs. the recirculation rate predicted by the Reynold/Grashof correlation.

Recommended correlation for the calculation of the wetting rate

Of the three calculation methods presented above (equations 6, 7 and 8), the recirculation rate calculated in equation 6 in kg/min/tube is not easily transferrable to a tube of a different diameter. Dividing the recirculation rate by the wetted perimeter, a correlation for the wetting rate (equation 7) is considered to be more useful and can be used for tubes of different dimensions. In comparison to the wetting rate correlation, the Reynold/Grashof equation based on heat transfer theory correlates well with an R^2 value of 0.8757. However, the heat transfer correlation predicts a Reynold number higher than that of the wetting rate correlation, implying a higher recirculation rate. The Reynold/Grashof analogy is therefore believed to be the most robust and conservative.

Interpretation of the dimensionless numbers for a single evaporator

A graph of the Reynold number vs Grashof number generated using equations 12 and 8 can be seen in Figure 12 for a second effect evaporator with juice of 19.8% brix and a steam temperature of 114°C. The temperature driving force ranges from 5.8 to 25°C.

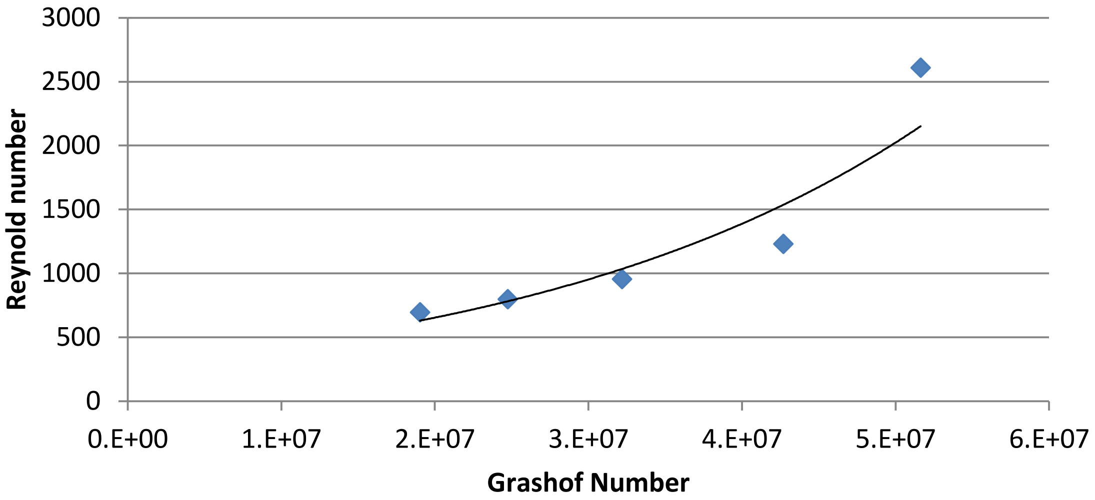

Figure 12. Reynold number vs. Grashof number for a second effect evaporator.

From Figure 12, it can be seen that the Reynold number is predominantly less than 2100, indicating that the flow regime at the tube entrance is laminar. The Reynold number at the largest temperature difference of 25°C was found to be 2606 and is thus transitioning to turbulent flow.

The Grashof number is seen to be very large, of the order of 10^7, indicating that buoyancy forces are dominant, as would be expected for natural convective boiling. The Prandtl number for this second effect evaporator was calculated according to equation 13 below and was found to be between 4.95 and 5.09.

$$\mathrm{Pr} = \frac{C_p . \mu}{k} \qquad \text{Eq 13}$$

The Prandtl number is defined as the ratio of momentum and thermal diffusivities (Incropera and De Witt, 2002) where a small Prandtl number implies large thermal diffusivity and thus a rapid diffusion of heat energy which can be attributed to a relatively low juice viscosity.

Interpretation of the dimensionless numbers for a set of evaporators

For a quintuple set of evaporators, the Reynold, Grashof and Prandtl numbers were calculated according to equations 12, 8 and 13, respectively. In addition, the optimum recirculation rate and liquid level were calculated according to equations 6 and 5, respectively, and these are summarised in Table 3 below.

Table 3. Summary of dimensionless numbers for a set of Robert evaporators.

Evaporator effect	2nd	3rd	4th	5th
Reynold number	612.83	557.92	537.44	465.55
Grashof number	1.39E+07	1.00E+07	8.47E+06	2.53E+06
Prandtl Number	2.82	4.19	5.98	12.90
Minimum recirculation rate (kg/min/tube)	0.57	0.77	1.04	1.93
Liquid level as a fraction of tube height	0.52	0.48	0.42	0.35

The Prandtl number is seen to steadily increase from a value of 2.82 in the second effect to a value of 12.90 in the final effect evaporator. The increase in the Prandtl number with each effect is to be expected, and implies that the diffusion of heat energy is increasingly slow as the viscosity of the juice is increased with each evaporator effect.

As the viscosity is increased with each effect, boiling due to natural convection is reduced, as can be seen by a trend of decreasing Grashof numbers from 1.39×10^7 to 2.53×10^6.

To increase the rate of heat transfer in the final effect, a higher recirculation rate is required, and this is evident in the trend of increasing recirculation rate with increased evaporator effects from 0.57 to 1.93 kg/min/tube. A trend of reducing liquid levels with each evaporator effect, as expected by Hugot (1972), is evident and will aid in reducing the boiling point elevation due to hydrostatic head whilst maintaining sufficient wetting of the tubes. This trend in the liquid level was found to contradict the findings of Broadfoot and Dunn (2007) who reported a trend of increasing liquid level with increased juice brix. The liquid level calculation is, however, highly dependent on the available temperature difference, which is in turn dependant on the dynamics of the system, and could vary from one mill to the next.

Conclusion

Based on heat transfer theory, it is evident that a higher juice velocity through the tubes in a Robert evaporator reduces the thickness of the velocity and thermal boundary layers, thus increasing the convective heat transfer coefficient. This increase in the juice velocity is best achieved by recirculation of juice through a semi-sealed down-take. The off-take cone in the down-take should be positioned at an optimum height to ensure the maximum heat transfer coefficient while maintaining constant wetting of the tubes. The off-take diameter can be calculated based on the required recirculation rate, where a large amount of recirculation would imply a smaller off-take cone diameter in relation to the down-take diameter. The minimum liquid level can be calculated according to equation 5 and the optimum recirculation rate can be calculated from the Reynold/Grashof correlation in equation 12. This correlation is based on heat transfer theory and is believed be most conservative, taking into account varying tube diameters and thus allowing for optimum heat transfer in a Robert evaporator.

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APPENDIX 1.
SUMMARY OF EQUATIONS FOR THE GRAPHS OF (GUO *ET AL.*, 1983)

Table 4. Equations describing the trend of heat transfer coefficient (HTC) rising with increased liquid level.

Increasing Heat Transfer Co-efficient	
ΔT	HTC (kW/m^2.K) vs. liquid level (m)
5.8	$y = -184.77x^2 + 161.04x - 31.692$
7.6	$y = -189.09x^2 + 148.75x - 25.962$
10	$y = -180.42x^2 + 134.63x - 21.81$
13.5	$y = -13.35x^2 + 74.5x - 8.8802$
17.5	$y = -112.1x^2 + 67.514x - 6.8504$

Table 5. Equations describing the trend of heat transfer coefficient (HTC) reducing with increased liquid level.

Decreasing Heat Transfer Co-efficient	
ΔT	HTC (kW/m^2.K) vs. liquid level (m)
5.8	$y = -0.0753x^2 - 2.5057x + 4.4711$
7.6	$y = -0.1325x^2 - 2.3884x +4.2276$
10	$y = -0.3717x^2 - 2.0799x + 4.1239$
13.5	$y = -0.3115x^2 - 2.2061x + 4.1428$
17.5	$y = -1.5141x^2 - 0.8556x +3.6954$

Table 6. Equations describing the relationship between recirculation rate, liquid level and temperature driving force.

ΔT	Recirc rate (kg/s) vs. liquid level (m)
5.8	$y = 0.7889x - 0.3577$
7.6	$y = 0.9026x - 0.3838$
10	$y = 1.1542x -0.459$
13.5	$y = 1.0971x - 0.3249$
17.5	$y = 1.6489x - 0.4059$

Note: The recirculation rate reported above is the total value and should be divided by three to obtain the recirculation rate per tube.

APPENDIX 2.
SUMMARY OF THE DATA USED IN THE DEVELOPMENT OF THE REYNOLD/GRASHOF CORRELATION.

Table 7. Summary of the data of Guo *et al*. (1983) used in the development of the Reynold/Grashof correlation.

Temperature driving force	Steam temperature	Juice brix
^{0}C	^{0}C	%
5.8	105.8	0 (Water)
7.6	107.6	0 (Water)
10	110	0 (Water)
13.5	113.5	0 (Water)
17.5	117.5	0 (Water)

Table 8. Summary of the data from Tongaat Hulett factories used in the development of the Reynold/Grashof correlation.

Temperature driving force	Steam temperature	Juice brix
^{0}C	^{0}C	%
6	120	11.9
4.1	114	19.8
6.5	97.4	26.8
10.9	89.4	32.5
9.7	109.8	19.8
15.1	99.1	24.7
10.3	97.6	34.1