EVAPORATION PROCESS IMPROVEMENT USING PRECALCULATED VALUES FOR JUICE INJECTION FLOW TO FIFTH EFFECT

By

F.E. RODRÍGUEZ, E.A. BAUTISTA and J.L. ALFARO

Ingenio La Unión S.A., Guatemala, C.A.

fquezada@launion.com.gt

Abstract

THIS WORK presents a method for improving the evaporation train performance through a pre-calculated value for injection of clarified juice at the last effect. Previously, when the concentration of syrup was above set point, the juice injection valve remained fully open causing an upset in the stability of levels of the last effect vessels as well as in the temperatures. With measurements of juice flow going to the pre-evaporators, saturated vapour flow, temperatures, as well as effective heat transfer areas (EHTAs), values for the outcomes of each effect as well as condensate flows are calculated. In order to estimate vapour bleeding, the EHTA for each effect is calculated through heat transfer coefficients, estimated condensate flows and measured vapour and juice temperatures. EHTAs and the area of the calandria tubes in contact with steam must match and this is the criterion to estimate condensate flows. Computed values come directly from mass and energy balances over the evaporator set as a whole. Temperature corrected values for latent heat and heat capacity at constant pressure at each effect are used. Factory tests using the syrup flow calculated to control the juice injection valve at the fifth effect demonstrated operation with less overshoot in vapour and juice temperatures on last effect, stability of levels of the last effect vessels,, and the brix of the syrup became more stable. These improvements show that this model of the evaporation process yields a value for the flow of syrup that is useful to make the juice injection valve dependent not only on the concentration of the syrup but also on the performance of the whole evaporator set. As the syrup flow increases, more clarified juice can be injected into the final effect and vice versa, and less juice is injected as the syrup flow decreases.

Introduction

Motivated by the optimisation of the evaporation station, the investigation group started to develop concentration profiles for all vessels involved. They discovered that the fourth effect vessel always reached up to 73 brix, meanwhile the output of the last effect was being diluted to 50–55 brix. The reason was that the valve controlling the injection of clarified juice opened 100% in a very short time, even though the evaporation throughput was minimal. The temperature and the amount of the juice injected caused instability in the level, syrup concentration oscillations and reduced the capacity of the fourth and fifth effect vessels.

Evaporation station description

There are two trains of evaporators at La Union Sugar Mill, one for the raw sugar line and the other for the white sugar line. Each set consists of nine vessels. The white sugar line takes juice only from the first mill, and the rest of the juice and imbibition water go to the raw sugar evaporator line.

Juice is pumped into the first effect from a separate tank for each line. To this effect, the exhaust steam is added in parallel, that is, to the four vessels from the same source as shown in Figure 1. The liquor concentrated in the first effect is sent to the feed of the second effect, and so on through all five effects. Inside each effect the juice is fed in series from one vessel to the following.
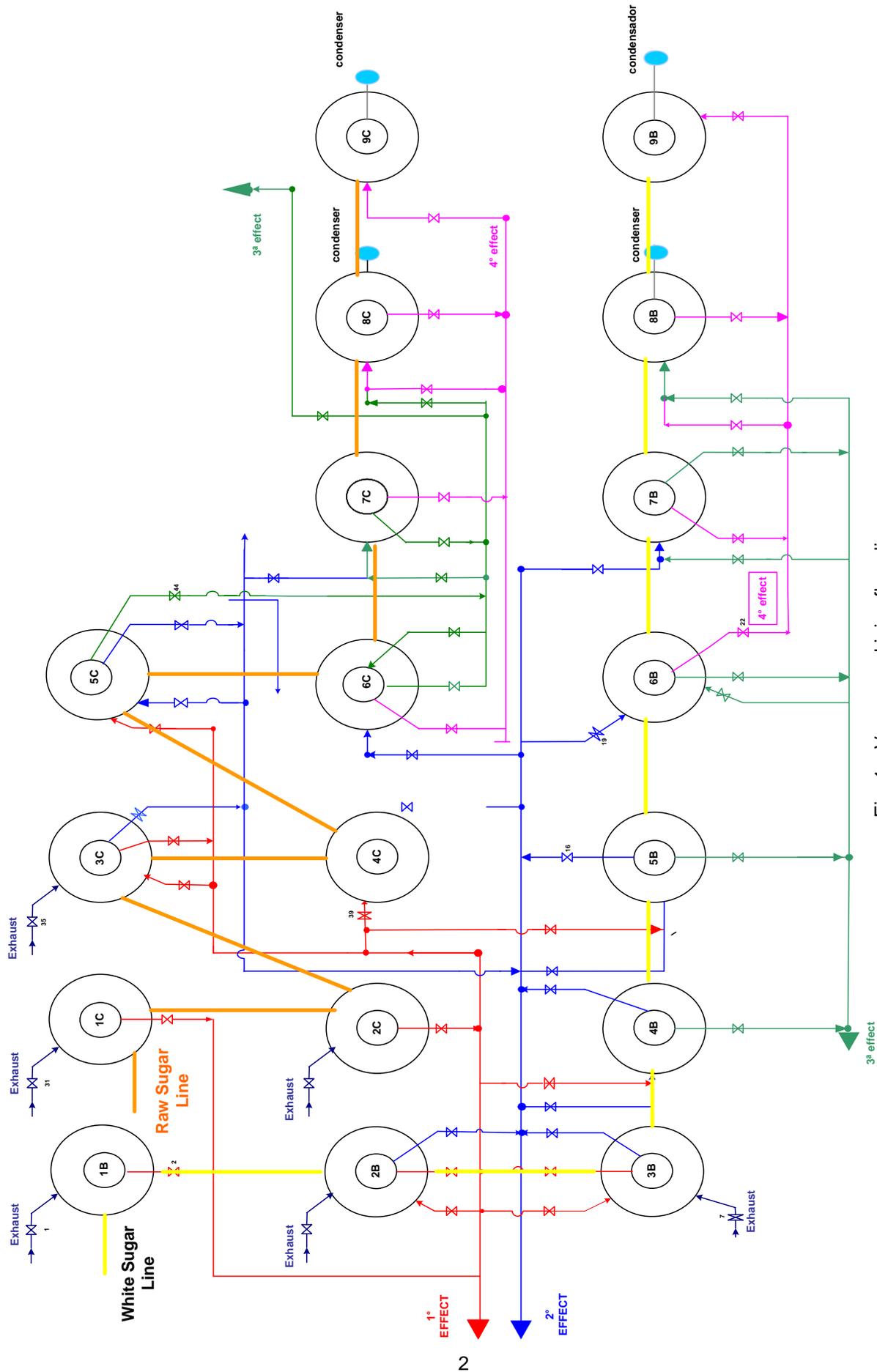
Fig. 1—Vapour and juice flow diagram.

_____

Traditional brix control applied

The control used to maintain the concentration of the syrup at a constant value, usually 65 Bx, is located at the end of the evaporators. A sample of the syrup comes out from a fixed point, its measured value (DT) is taken to a proportional plus integral control block which acts on two automatic valves whose control logic to maintain the given set point is as follows:

- If the measured brix is above the set point, the controller acts on the clarified juice injection control valve to the entrance of the last evaporator, governing clarified juice injection to reduce the concentration, or

- If the syrup brix is below set point, the controller acts on the syrup recirculation valve, also on the last evaporator, which recycles syrup back to the inlet of the last effect to evaporate it again, so the brix set point will be reached.

The regulation of these valves is done one at a time, which means that the valves will never be acting at the same time, if the injection valve is regulating, the syrup recirculation valve will be closed and vice versa.

The model-based brix control

A limit was imposed on the juice injection valve to make its 100% opening correspond to the maximum calculated syrup flow observed, which was around 60 kg/s. If the evaporation throughput diminished for any reason, the valve would follow the new limit (closes a corresponding percentage) regulating clarified juice injection to the fifth effect.

For about half an hour on two different days, brix samples were obtained from consecutive vessels to build the brix profiles shown in Tables 1 and 2, at the same time the new control was applied. These do not show any abnormal concentration in the 4th effect as would have been if the profile were done for example half an hour earlier, as can be seen in Figures 3 and 6, when there were periods of syrup brix below set point as well as signs of instability in the rest of the graphs.

Table 1—Concentration profile along the evaporator set 04–05–2009 at 14:36.

Operation with injection valve limiting	Clarified juice	Pre-evaporator		2nd Effect		3rd Effect		4th Effect	5th Effect
		1C	2C	3C	4C	5C	6C	7C	8C
Brix 4/05/09 every 3 min	12.5	16.6	17.9	23.4	27.4	35.8	48.0	58.9	62.8

Table 2—Concentration profile along the evaporator set 05–05–2009 at 10:32.

Operation with injection valve limiting	Clarified juice	Pre-evaporator		2nd Effect		3rd Effect		4th Effect	5th Effect
		1C	2C	3C	4C	5C	6C	7C	9C
Brix 5/05/09 every 3 min	11.7	15.2	17.7	22.6	28.1	36.4	39.5	51.3	64.4

All of the other brix profiles done by the investigation group showed a strayed pattern in the 4th effect with concentrations greater than 70 brix.

The graphs from Figure 2 to Figure 4 show the behaviour of the process variables involved when the control was applied for 48 minutes from 14:14 to 15:02 on 04/05/09, during the time the concentration profile of Table 1 was performed.

Figure 2 shows stabilisation of the levels in vessels 5, 6, 7 and 8 fifteen minutes after the controller started to work. Figure 3 shows stabilised syrup concentration, the regulation applied to the injection valve as well as total effective heat transfer area stabilisation. Figure 4 shows the absence of overshoots on the temperatures in vessels 6, 7 and 8 ten minutes after the control was applied (vessel 9 was being washed at the time).
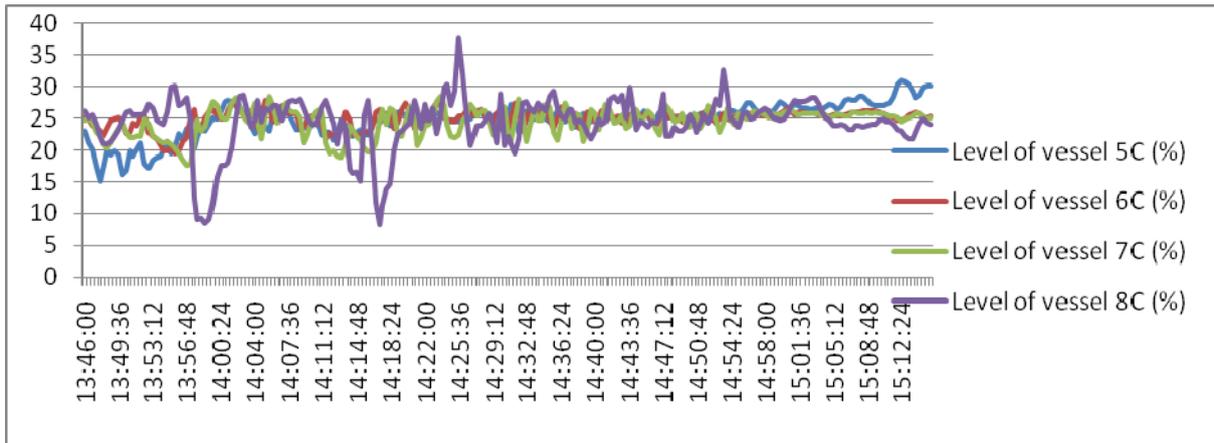
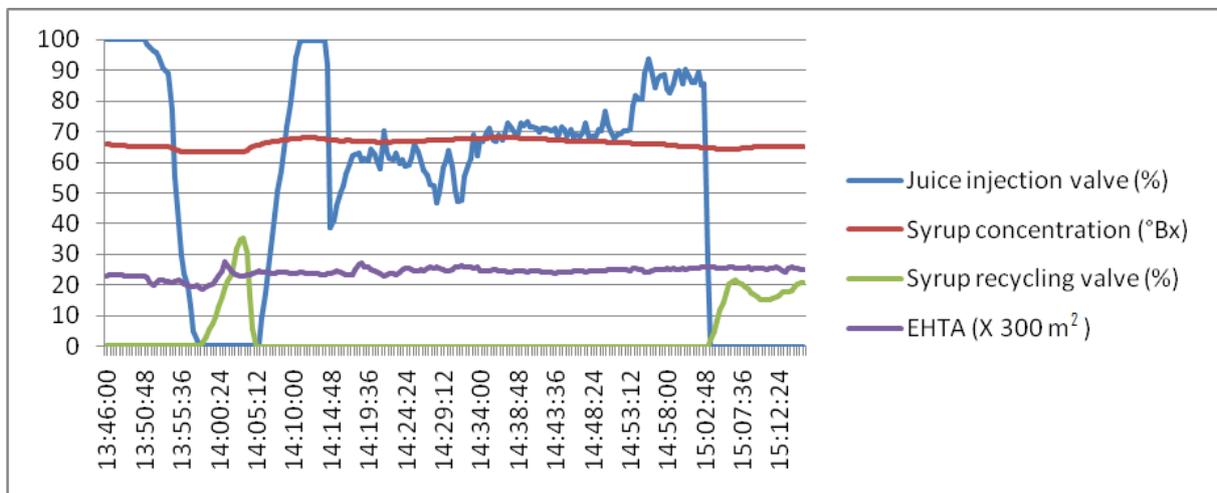Fig. 2—Trends for level of vessels from 3rd to 5th effect (radar sensors).

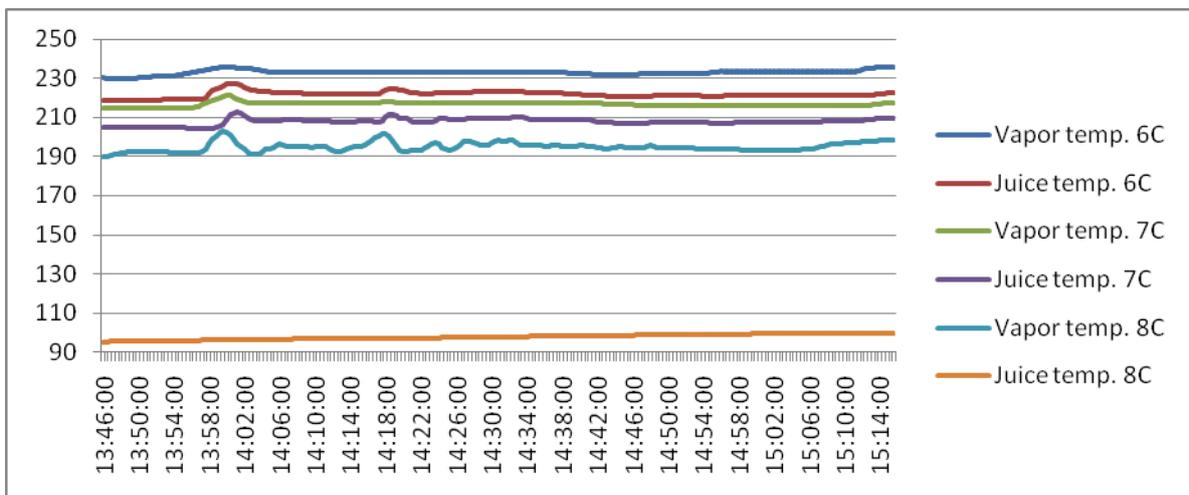Fig. 3—Trends for valve positions, brix and EHTA.

Fig. 4—Trends for vapour and juice temperatures from 3rd to 5th effect.

The graphs from Figure 5 to Figure 7 show the behaviour of the process variables involved when the control was applied for almost an hour, from 10:24 to 11:21 on 5–05–09.
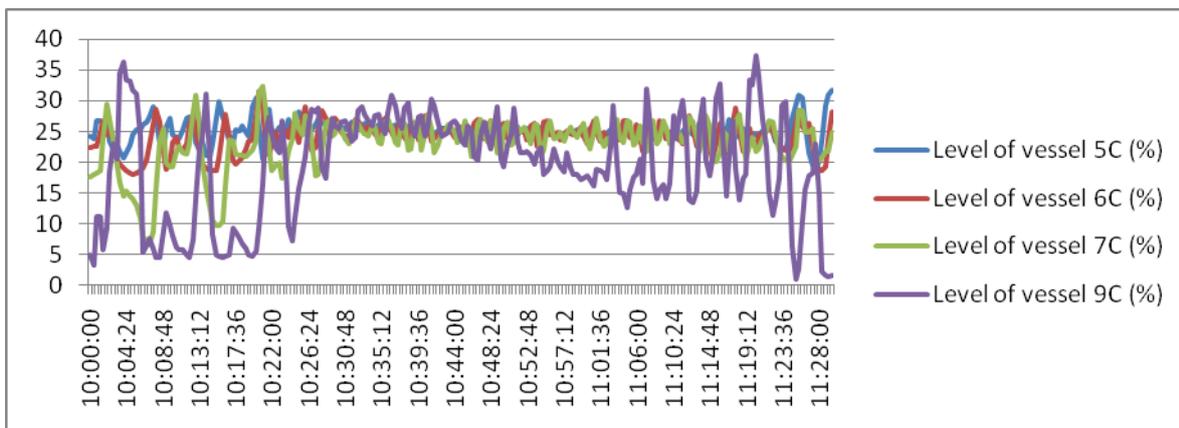
Fig. 5—Level in vessels from 3rd to 5th effect (radar sensors).
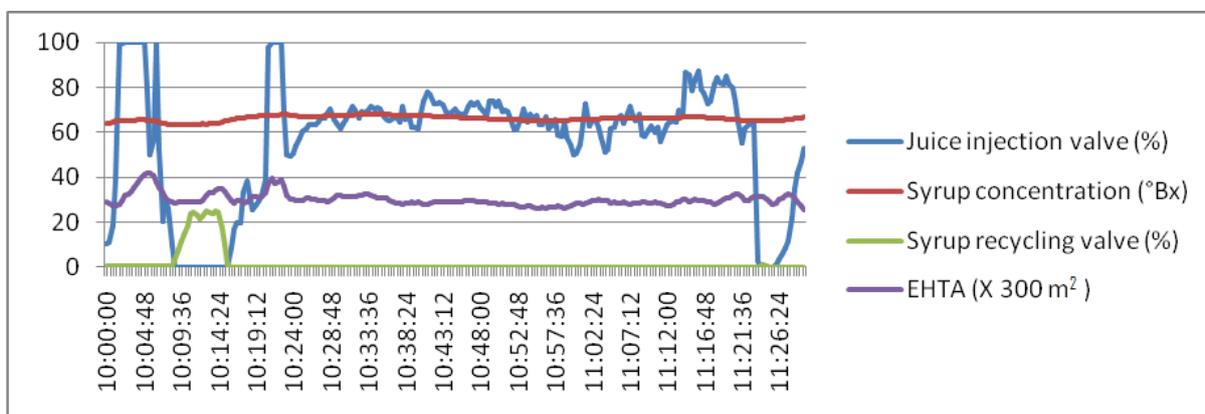

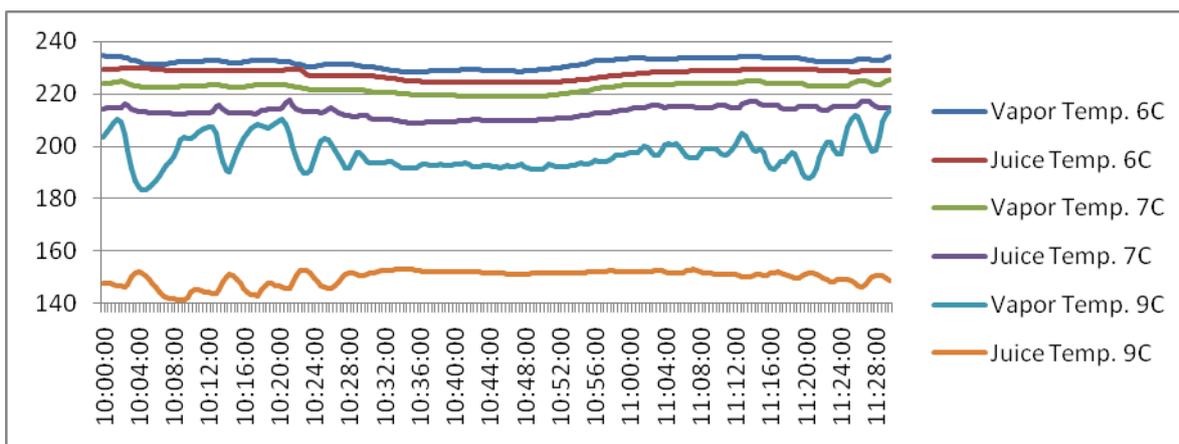Fig. 6—Trends for valve positions, brix and EHTA.

Fig. 7—Trends for vapour and juice temperatures from 3rd to 5th effect.

The effects on the performance of the evaporator set are greater on the experience the following day. During this time the concentration profile of Table 2 was performed and the stabilisation on levels is evident in Figure 5. The cycling of the syrup recirculation valve with unregulated juice injection valve is shown in Figure 6 for the period immediately before the application of the control, when the PID control was not able to control the process, coincidently

with instability of the last effect level (vessel #9).

Of course, it is possible that the PID control was not properly tuned and it acted as an ON-OFF control. Other experiences were performed anyway on those last days of the sugarcane harvest, but were few because the cane supply was low. These results are not shown here because no brix profiles like those of Tables 1 and 2 were collected. The experiences could not be made when the syrup recycling valve was opened, and it was necessary to wait for the juice injection valve to open in order to apply the controller.

Some comments on effective heat transfer areas

A very important concept in the development of this model is that of EHTA, because it supplies the criteria to estimate, at any time, the amount of vapour bleeding to the evaporator set. The concept has to be refined since the heat transfer coefficients of the evaporators at La Union Sugar Mill are in the process of being measured this coming harvest, and the values used are the standards found in literature. The temperature differences were also too large and logarithmic mean temperature differences should be used. However, its immediate consequence is to show which effect is being bled and to what amount, since otherwise those areas were totally oversized as compared to those not being bled and proportions between effective and 'real' (calandria tubes areas) are kept.

Conclusions

- The proposed model offers a good approximation of the vapour bleeding effects on the evaporation train.

- The advantages of continuous instead of traditional batch operation come mainly from the fact that these kinds of simple models can be applied for control, which lead to simple and better operation.

- The equation found (24), computes the flow of syrup with the advantage that this value is not affected by the level regulation control on the last effect, as the flow of syrup being measured is obviously affected.

- Introduction of the controlled clarified juice into the process accelerates the dynamics in order to achieve steady state conditions on this naturally stable process. On equation (4), $\tau = V/F_{oP} \approx 6$ min is visibly reduced, as can be observed in Figure 4, by just keeping syrup flow as constant as possible (with help of the clarified juice to remove variations of flow), since clarified juice brix at the entrance of first effect seldom varies, once imbibition has been set, unless wash water from crystallisers is discharged.

Acknowledgments

REFERENCE

Smith, J.M., Van Ness, H.C. and Abbott, M.M. (2001). Correlation for latent heat of vaporisation, enthalpy, and heat capacity of condensates. Introduction to Chemical Engineering Thermodynamics, 4th ed., McGraw Hill.

_____

Apendix A

A model for the evaporator set

A model was proposed to calculate the effective heat transfer area by means of the total heat transferred, the heat transfer coefficient and the vapour-juice temperature differentials. One of the by-products of these calculations was the amount of juice not evaporated from each effect which, in the case of the last effect, resulted in the amount of syrup produced and the capacity of governing the clarified juice injection valve with this predicted value.

Model assumptions

- By watching the syrup leaving the final effect, it was evident that it was not too viscous, therefore its properties were still very close to those of the water. So it was decided to assume that heat capacities of juice were those of water and only after watching the results could it be decided what corrections should be made. Otherwise, brix at each vessel should be measured to adjust heat capacities. It was found that the model worked and, after looking for precision, we found that with a brix span of 10 °Bx the heat capacity difference between juice coming and leaving a vessel was less than 5% as computed on internet site http://www.sugartech.co.za/heatcapacity/index.php. In this way, uncertainties coming from brix variations were avoided.

- Mass and energy balances were stated assuming no accumulations or losses of energy and/or matter on vessels, that is, we assumed stability in temperatures and levels. However, for the first effect only, a transient term was included, just to get an idea of the improvements achieved when the controlled variable (clarified juice to fifth effect) is added to the equations, which obviously is a feedback term because it was calculated in terms of the syrup flow which in turn is calculated from values of clarified juice and saturated vapour flow.

Measurements already on site, and those added for our goals, were all steam flows (before and after vapour bleeding), all juice flows into and out of each effect as well as all vapour, juice and condensate temperatures.

Process flows around evaporator station (kg/s)

F_E	Exhaust Steam
F_{1F}	1st effect vapour flow
F_{1F}^t	1st effect vapour flow after vapour bleeding
F_{2F}	2nd effect vapour flow
F_{2F}'	2nd effect vapour flow after vapour bleeding
F_{3F}	3rd effect vapour flow
F_{3F}'	3rd effect vapour flow after vapour bleeding
F_{4F}	4th effect vapour flow
F_{iP}	Juice flow to pre evaporator
F_{oP}	Juice flow from 1st effect
F_{oD}	Juice flow from 2nd effect
F_{oT}	Juice flow from 3rd effect
F_{oF}	Juice flow from 4th effect
F_{oM}	Juice flow from 5th effect

Temperatures (°C)

T_E	Exhaust steam temperature
T_{1F}	1st effect temperature
T_{2F}	2nd effect temperature

_____

T_{3F} 3rd effect temperature
T_{4F} 4th effect temperature
T_{5F} 5th effect temperature
T_1 Juice temperature going to pre-evaporator
T_2 Juice temperature going from pre-evaporator
T_3 Juice temperature going from 2nd effect
T_4 Juice temperature going from 3rd effect
T_5 Juice temperature going from 4th effect
T_6 Juice temperature going from 5th effect
T_{cE} Exhaust steam condensate temperature
T_{c1F} 1st effect condensate temperature
T_{c2F} 2nd effect condensate temperature
T_{c3F} 3rd effect condensate temperature
T_{c4F} 4th effect condensate temperature

Parameters

C^P_{Tx} Heat capacity at constant pressure at temperature T_x (kJ/kg/°C)
λ_{Tx} Latent heat of vaporisation at temperature T_x (kJ/kg)

In this work the correlations given in Table 3 were used to calculate heat capacity at constant pressure (C^P_{Tx}) and latent heat of vaporisation (λ_{Tx}).

Table 3—Correlation for latent heat of vaporisation, enthalpy, and
heat capacity of condensates (Smith *et al.*, 2001).

Property (Pp)	a_o	a_1	a_2	a_3	a_4	R^2	Temperature range (ºC)
λ	2500.7	−2.3173	−0.0004	−5*10^{-06}	−3*10^{-08}	1	40 to 180
C_{PW}	4.1586	0.0006	−6*10^{-06}	5*10^{-08}		1	40 to 180

where $Pp = a_o + a_1T + a_2T^2 + a_3T^3 + a_4T^4$

Development of the model

Transfer area for the first effect is calculated from the expression used to define convection heat transfer:

$$A_{1F} = \frac{F_E \lambda_E}{U_{1F}(T_E - T_2)}$$

(1)

where F_E is exhaust steam flow measured through the condensates produced, λ_E is latent heat of vaporisation of water at exhaust steam temperature T_E, T_2 is juice temperature from first effect, and U_{1F} is the heat transfer coefficient of first effect.

To determine the flow exiting first effect vessels, an energy balance equation is used on the juice side:

$$\rho V C_{p2} \frac{dT_2}{dt} = \rho F_{iP} C_{p1} T_1 - \rho F_{oP} C_{p2} T_2 - \rho F_{1F} \lambda_{1F} + Q$$

(2)

where Q is the convection heat, namely UA[LMTD]. On the vapour side:

$$\rho V_{cE} C_{pcE} \frac{dT_{cE}}{dt} = \rho F_E \lambda_E - \rho F_E C_{PcE} T_{cE} - Q$$

(3)

_____

From mass balance equation, we made the simplifying assumption that the flow of vapour F_E is of the same value as the flow of condensates used in the previous equation. Assuming also V_{cE}, the amount of condensate remaining in the calandria to be 0 we obtain from (3) an expression for Q and substituting this into (2), after rearranging terms, we get:

$$\frac{V}{F_{oP}}\frac{dT_2}{dt} + T_2 = \frac{F_{iP}C_{p1}}{F_{oP}C_{p2}}T_1 - \frac{F_E C_{PcE}}{F_{oP}C_{p2}}T_{cE} + \frac{F_E \lambda_E}{F_{oP}C_{p2}} - \frac{F_{1F}\lambda_{1F}}{F_{oP}C_{p2}}$$

(4)

This is an equation of the form:

$$\tau\frac{dy}{dt} + y(t) = Kx(t)$$

(5)

where $\tau = V/F_{oP} \approx 2$ min (volume of calandria is roughly 9 m^3 and flow of juice from first effect is 4.5 m^3 per minute),
whose integrating factor is:

$$p(t) = exp\int\frac{dt}{\tau} = e^{t/\tau}$$

(6)

and the solution is:

$$y(t) = y_0 e^{-(t-t_0)/\tau} + \frac{K}{\tau}e^{-t/\tau}\int_{t_0}^{t}e^{t/\tau}x(t)dt$$

(7)

As soon as three times τ (≈ 6 min.), steady state conditions exist. However, on closed loop, this time will be diminished substantially and (4) can be simplified by:

$$F_E\lambda_E + F_{iP}C_{P1}T_1 = F_{1F}\lambda_{1F} + F_{oP}C_{P2}T_2 + F_E C_{PcE}T_{cE}$$

(8)

From mass balance equation, we get $F_{1F} = F_{iP} - F_{oP}$ so Eq. No. (8) becomes an expression to calculate F_{oP}:

$$F_{oP} = \frac{F_{iP}(\lambda_{1F} - C_{P1}T_1) - F_E(\lambda_E - C_{PcE}T_{cE})}{(\lambda_{1F} - C_{P2}T_2)}$$

(9)

This equation can easily be checked for two extremes.

1.   In the case F_{oP} turns out to be zero we have all juice transformed into vapour:

$$F_E(\lambda_E - C_{PcE}T_{cE}) = F_{iP}(\lambda_{1F} - C_{P1}T_1)$$

(10)

2.   If F_E is too small, we would have no evaporation which means: $F_{iP} = F_{oP}$, the approximation $C_{P1} \approx C_{P2} = C_P$ as usual, and substituting these two expressions into (9) to yield the known expression for heating a liquid:

$$F_E(\lambda_E - C_{PcE}T_{cE}) = F_{iP}C_P(T_2 - T_1)$$

(11).

_____

Transfer area for second effect or Duplex is calculated the same way, except that care must be taken because the first effect vapour flow that enters into the vessels is not anymore $F_{iP} - F_{oP}$ and has to be measured because of vapour bleeding. By means of gauging condensate tanks for exhaust steam as well as for first effect vapour, in the experiment the following relationship has been found:

$$F'_{1F} = 0.6\,F_E \tag{12}$$

and

$$A_{2F} = \frac{0.6 F_E \lambda_{1F}}{U_{2F}(T_{1F} - T_3)} \tag{13}$$

At this point, use of the concept of EHTA is starting to be important, as explained at the end of the main body of the paper. To measure the flow of vapour bleeding, we would have to make major changes in the distribution of tanks and tubes at the bottom of the evaporator set, because at this time they are mixed and pumped to the boiler. At other times, we also tried to measure the vapour, but the problem was with the sensors, since changes of pressure were too small to be measured. What is being proposed is that the model has to be calibrated constantly because the flow of clarified juice F_{iP} and the flow of Exhaust Steam F_E, have different time-scale variations. In this experiment, the values (0.6, 0.33, and 1) were used to take account of vapour bleeding, but it will necessarily have to be changed according to the comparison criteria, that is, comparing EHTAs (effective heat transfer areas) computed with the areas of the tubes of heat exchangers in contact with steam. In future experiments, maybe this can be automated by setting up a range of valid variations of EHTA as compared with 'real' values of the sum of the areas of the tubes of the calandria.

By means of similar expressions to (8) and (9), we get the output flow of second effect:

$$F_{oD} = \frac{F_{oP}(\lambda_{2F} - C_{P2}T_2) - 0.6F_E(\lambda_{1F} - C_{PC1F}T_{c1F})}{(\lambda_{2F} - C_{P3}T_3)} \tag{14}$$

This is the flow of juice to the 3rd effect vessels. To determine vapour flow of the second effect (later, the same procedure was applied to first effect), we compared on stable conditions the effective area of third effect, which was around 13 000 m^2, to the measured area of the heat exchanger tubes, roughly 4600 m^2, and observed an approximate 3 to 1 ratio which means that 66% vapour bleeding was made to this effect. Thus:

$$F'_{2F} = 0.33(F_{oP} - F_{oD}) \tag{15}$$

The effective area for the third effect as well as the juice flow are computed from the following equations:

$$A_{3F} = \frac{0.33(F_{oP} - F_{oD})\lambda_{2F}}{U_{3F}(T_{2F} - T_4)} \tag{16}$$

$$F_{oT} = \frac{F_{oD}(\lambda_{3F} - C_{P3}T_3) - 0.33(F_{oP} - F_{oD})(\lambda_{2F} - C_{PC2F}T_{c2F})}{(\lambda_{3F} - C_{P4}T_4)} \tag{17}$$

_____

Vapour bleeding on third effect was ignored by mistake (see Figure 1), but coincidently T_5 was improperly installed, as shown on simulation stage (not included in this paper because it was a simple excel sheet), compensating for the mistake, so the equation remains as:

$$F_{3F} = F_{oB} - F_{oT} \tag{18}$$

$$A_{4F} = \frac{F_{3F}\lambda_{3F}}{U_{4F}(T_{3F} - T_5)} \tag{19}$$

$$F_{oF} = \frac{F_{oT}(\lambda_{4F} - C_{P4}T_4) - F_{3F}(\lambda_{3F} - C_{Pc3F}T_{c3F})}{(\lambda_{4F} - C_{P5}T_5)} \tag{20}$$

$$F_{4F} = F_{oT} - F_{oF} \tag{21}$$

$$A_{5F} = \frac{F_{4F}\lambda_{4F}}{U_{5F}(T_{4F} - T_6)} \tag{22}$$

$$F_{oM} = \frac{F_{oF}(\lambda_{5F} - C_{P5}T_5) - F_{4F}(\lambda_{4F} - C_{Pc4F}T_{c4F})}{(\lambda_{5F} - C_{P6}T_6)} \tag{23}$$

After doing all substitutions, we get for F_{oM}:

$$F_{oM} = \sum_{j=1}^{17} K_j \tau_j F_{iP} + \sum_{j=1}^{29} K_j' \tau_j' F_E \tag{24}$$

where F_{iP} is juice flow and F_E exhaust steam,

$$\tau_j = \prod_{i=1, i \neq j}^{5} \frac{(\lambda_{iF} - C_{Pi}T_i)(\lambda_{jF} - C_{PcjF}T_{cjF})}{(\lambda_{iF} - C_{P(i+1)}T_{(i+1)})}$$

and

$$\tau_j' = \prod_{i=0, i \neq j}^{5} \frac{(\lambda_{iF} - C_{PciF}T_{ciF})(\lambda_{jF} - C_{Pj}T_j)}{(\lambda_{iF} - C_{P(i+1)}T_{(i+1)})}$$

PREDETERMINATION DU JUS INJECTE DANS LE CINQUIÈME EFFET POUR AMÉLIORER L'ÉVAPORATION

Par

F.E. RODRÍGUEZ, E.A. BAUTISTA et J.L. ALFARO

Ingenio La Unión S.A., Guatemala, C.A.
fquezada@launion.com.gt

MOTS-CLEFS: **Transfert de Chaleur Effectif, Injection de Jus, Concentration du Sirop, le Processus d'Évaporation.**

Résumé

CE TRAVAIL présente une méthode pour améliorer la performance des évaporateurs par l'injection prédéterminée de jus clarifié dans le dernier effet. Auparavant, lorsque la concentration du sirop était au-dessus de la norme, la vanne d'injection de jus restait complètement ouverte, affectant la stabilité des niveaux des dernières effets ainsi que les températures. On mesure les débits de jus aux pré évaporateurs, le débit de vapeur, les températures, ainsi que les surfaces pour le transfert de chaleur (EHTAs), pour calculer la performance de chaque effet ainsi que les débits des eaux condensées. Afin d'estimer les prélèvements de vapeur, la EHTA pour chaque effet est calculée par l'intermédiaire de coefficients de transfert de chaleur, des débits d'eaux condensées, et les températures de la vapeur et du jus. Les EHTAs et la surface des tubes de la calandre en contact avec la vapeur doivent correspondre et c'est le critère pour estimer les débits des eaux condensées. Les valeurs calculées proviennent directement de bilans de masse et d'énergie pour le train complet d'évaporateur. Les températures sont corrigées pour les effets des chaleurs latentes à pression constante pour chaque effet. Des essais en usine avec le sirop calculé pour contrôler la vanne d'injection du jus au cinquième effet ont donnes une consommation de vapeur, des températures et un Brix plus stables au dernier effet. Ces améliorations montrent que ce modèle d'évaporation donne de bons résultats pour le train d'évaporateurs. Comme le débit de sirop augmente, plus de jus clarifié est injectée dans l'effet final et vice versa.

USO DE LA MEJORA DEL PROCESO DE EVAPORACIÓN PRECALCULADOS VALORES PARA LA INYECCIÓN DE JUGO EL FLUJO AL EFECTO QUINTO

Por

F.E. RODRÍGUEZ, E.A. BAUTISTA y J.L. ALFARO
Ingenio La Unión S.A., Guatemala, C.A.
fquezada@launion.com.gt

Resumen

ESTE TRABAJO presenta un método para mejorar el rendimiento del tren de evaporación por medio de valores pre-calculados del jugo claro de inyección en el último efecto. Con anterioridad, cuando la concentración de la meladura estaba arriba de la consigna, la válvula de inyección de jugo acostumbraba quedarse todo el tiempo abierta ocasionando inestabilidad en los niveles de los vasos en los últimos efectos asimismo en las temperaturas. Con mediciones del flujo de jugo a los pre-evaporadores, flujo de vapor saturado, temperaturas y las áreas efectivas de transferencia de calor AETCs se calculan los productos de cada efecto así como los flujos de condensados. Para estimar las sangrías o extracciones el AETC para cada efecto se calcula por medio de los coeficientes de transferencia de calor, flujos de condensado estimados y temperaturas medidas de jugo y vapor. AETCs y las áreas de los tubos de la calandria en contacto con el vapor deben ser iguales y este es el criterio para estimar los flujos de condensados. Los valores calculados salen directamente de balances de masa y energía sobre el tren de evaporadores como un todo. Se usan valores corregidos por temperatura del calor latente y la capacidad calorífica a presión constante en cada efecto. Mediante pruebas en campo usando el flujo de meladura calculado para controlar la válvula de inyección de jugo en el quinto efecto se consiguió una operación más estable en las temperaturas del vapor y del jugo del último efecto, estabilidad en los niveles de los vasos de los últimos efectos y el brix de la meladura más estable. Estas mejoras muestran que este modelo del proceso de evaporación produce un valor para el flujo de meladura que es útil para hacer que la válvula de inyección de jugo claro no solo dependa de la concentración de la meladura sino también de la producción total del tren de evaporadores. Mientras el flujo de meladura aumenta, más jugo clarificado se puede inyectar en el quinto efecto y viceversa, se inyecta menos jugo si el flujo de meladura disminuye.