MAXIMISING REVENUE FROM SUGAR EXTRACTION AND COGENERATION THROUGH IMBIBITION RATE REGULATION

By

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Abstract

Operating data obtained from two factories were used to test the validity of the Hugot formula which quantifies mill extraction at various imbibitions % fibre for a constant cane crushing rate. Simulations were carried out through an energy balance to determine electricity production at different imbibition % fibre. The net and combined revenues obtained from sugar extraction and electricity production were determined and plotted against imbibition % fibre. Results show that, for each factory, there is an optimum imbibition % fibre that yields maximum revenue.

Introduction

Sugar recovery from cane (mill extraction) increases rapidly with increased imbibition at first, then slows down asymptotically to a constant. Steam consumption also increases with increased imbibition. When electricity is produced through cogeneration, there will obviously be an optimum imbibition rate, which corresponds to the maximum benefit obtainable. This optimum imbibition rate depends on the ratio of the price of sugar to the price of electricity. In order to optimise imbibition rate, the extraction obtainable at various levels of imbibition with the corresponding electricity production needs be quantified. Kong et al. (1992) attempted to estimate mill extraction at different imbibition rates through a regression equation relating pol % bagasse and imbibition % fibre. However, the correlation coefficient of the equation was found to be low (0.64).

This paper uses the formula derived by Hugot (1986) to determine the mill extraction at various imbibition rates. Corresponding decreases in electricity production were calculated through the use of steam balance software. The net and combined revenues obtained from sugar extraction and from electricity production were determined and plotted against imbibition % fibre to maximise the total revenue.

Materials and method

Operating data were obtained from two factories to test the validity of the formula used for estimating total mill extraction of the milling tandem at various imbibition rates. The formula, derived by Hugot (1986), is detailed below.

\[
\begin{align*}
\lambda &= \text{ratio of weight of imbibition water to weight of fibre;} \\
n &= \text{Number of imbibition stages.}
\end{align*}
\]

The mill extraction \( e \) of the milling tandem gives the theoretically extractable sugar. In order to convert that actually extracted, an efficiency factor \( B \) needs to be introduced, where \( B \) is defined below.

\[
B = \frac{\text{sugar actually extracted}}{\text{sugar theoretically extractable}}
\]

In order to account for the efficiency factor \( B \), \( \lambda \) in the above Hugot’s formula needs to be replaced by \( \lambda' \) where

\[
\lambda' = \frac{Br}{(1 - Br)}
\]

and

\[
r = \frac{\lambda}{\lambda + 1}
\]

Experiments were started at Mon Trésor sugar factory (MT) with fixed settings for cane crushing and imbibition rates. First mill bagasse was analysed on an hourly basis for a whole day to determine the fibre content per unit of first-mill bagasse and fibre content per unit cane. The imbibition rate, the ratio of weight of imbibition water to weight of fibre and the actual mill extraction were calculated using data from the daily factory report. These figures were used to calculate the efficiency factor \( B \). The experiment was then repeated for about 10 days keeping the cane crushing rate relatively constant but with different imbibition rates on each day. The efficiency factor \( B \) was plotted against the imbibition % fibre and the fibre rate, and the corresponding regression equations were then determined. Using the regression equations, the efficiency factor \( B \) was calculated for various imbibition % fibre, it was then used in simulations to determine the effect of imbibition % fibre on mill extraction using Hugot’s formula for specific conditions of the factory. With the knowledge of the mill extraction at different imbibition rates, the sugar extracted could be readily calculated and the surplus or shortfall of

KEYWORDS: Mill Extraction, Sugar Recovery, Cogeneration, Energy, Economics.
sugar extraction around a convenient datum determined. Actual mill extraction and fibre rate were also plotted against imbibition % fibre. The experiment was repeated at Union St Aubin sugar factory (USA).

The total amount of electricity that can be produced was calculated through an energy balance at the known turbo-alternator efficiency, and the process steam requirements based on the actual requirement of the factory. Using one appropriate imbibition % fibre as a datum, 230 and 150 for MT and USA respectively, the net revenue arising from excess or shortfall of sugar and electricity around that datum was determined for various imbibition rates. These specific imbibition % fibre values were used as datum as they are close to the actual working situation. The net and combined revenues arising from the excess or shortfall of sugar and electricity around the datum were calculated and plotted against imbibition % fibre.

Factory conditions

Energy use calculations are dependent on cane supply and other operational factors as well as on steam use arrangements in the juice processing section of the factory. It is not possible in this paper due to space limitations to provide all these details, although they are available from the authors should they be required. However, some brief details are provided in Table 1 which gives the average cane supply, extraction, recovery and other relevant details during the trials. The table indicates that there was extensive vapour bleeding in both factories.

<table>
<thead>
<tr>
<th></th>
<th>Mon Tresor</th>
<th>Union St Aubin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight of cane (tonnes)</td>
<td>301 038</td>
<td>284 152</td>
</tr>
<tr>
<td>Sucrose % cane</td>
<td>12.56</td>
<td>11.71</td>
</tr>
<tr>
<td>Fibre % cane</td>
<td>17.21</td>
<td>18.50</td>
</tr>
<tr>
<td>Crushing rate (t/h)</td>
<td>96.5</td>
<td>124.7</td>
</tr>
<tr>
<td>Fibre rate (t/h)</td>
<td>16.06</td>
<td>23.05</td>
</tr>
<tr>
<td>Fibre % bagasse 1st mill</td>
<td>35.88</td>
<td>33.04</td>
</tr>
<tr>
<td>Imbibition % fibre</td>
<td>230</td>
<td>152</td>
</tr>
<tr>
<td>Number of mills</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Mill extraction (%)</td>
<td>94.85</td>
<td>96.51</td>
</tr>
<tr>
<td>Factor B</td>
<td>0.8156</td>
<td>0.9881</td>
</tr>
<tr>
<td>Factor a (assumed)</td>
<td>1.05</td>
<td>1.05</td>
</tr>
<tr>
<td>Number of effects</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Exhaust steam pressure (kPa abs)</td>
<td>163.4</td>
<td>150.0</td>
</tr>
<tr>
<td>Low pressure steam used</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Heater 1</td>
<td>V3</td>
<td>V3</td>
</tr>
<tr>
<td>• Heater 2</td>
<td>V2</td>
<td>V2</td>
</tr>
<tr>
<td>• Heater 3</td>
<td>V1</td>
<td>V1</td>
</tr>
<tr>
<td>• Heater 4</td>
<td>V1</td>
<td>V1</td>
</tr>
<tr>
<td>• Clarified juice heater</td>
<td>V2</td>
<td>V2</td>
</tr>
<tr>
<td>• A pans</td>
<td>V1</td>
<td>V1</td>
</tr>
<tr>
<td>• B pans</td>
<td>V1</td>
<td>V1</td>
</tr>
<tr>
<td>• C pans</td>
<td>V1</td>
<td>V1</td>
</tr>
<tr>
<td>Boiling house recovery (%)</td>
<td>88.5</td>
<td>90.4</td>
</tr>
<tr>
<td>Sugar price (MUR/tonne)</td>
<td>12 500</td>
<td>12 500</td>
</tr>
<tr>
<td>Electricity price (MUR/kWh)</td>
<td>1.1865</td>
<td>1.2500</td>
</tr>
<tr>
<td>Turbo alternator efficiency (%)</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>Electricity produced (MWh)</td>
<td>27 514</td>
<td>21 387</td>
</tr>
</tbody>
</table>

Table 1—Operating factory conditions.

Results and discussion

Figures 1a and 1b show the variation of the efficiency factor B with the imbibition % fibre for the two sugar factories. MT and USA worked at an annual mean imbibition % fibre of 219 and 172 respectively for the 1999 season. MT is equipped with a four-mill tandem whereas USA has a five-mill tandem. The results of analyses and further details of assumptions used are given in Table 1. Regression coefficients of MT and USA are good with R² of 0.89 and 0.92 respectively. In both cases, it was found that the efficiency factor B decreased with an increase in the imbibition % fibre. Further, it can be observed that the value of the efficiency factor B was lower in the case of the factory with the higher imbibition % fibre.

![Graph](image1)

Fig. 1a—Variation in factor B with imbibition % fibre (Mon Tresor).

![Graph](image2)

Fig. 1b—Variation in factor B with imbibition % cane (Union St Aubin).

It is common knowledge that mill extraction is dependent on the fibre rate. Figures 2a, and 2b show the relationship between the efficiency factor B and the fibre rate in tonnes fibre per hour (TFH) for the two respective factories MT and USA with R² at 0.67 and 0.26 indicating poor linear regressions. One cannot therefore have a direct relationship between the efficiency factor B and fibre rate.

The relationship between mill extraction and imbibition % fibre is shown in Figures 3a and 3b for MT and USA respectively, with very low R² at 0.34 and 0.45. The regression equation relating mill extraction and imbibition % fibre cannot therefore be used directly for MT and USA. Since neither the fibre rate nor the relationship between mill extraction and imbibition % fibre could be used for estimating mill extraction, the relationship
between the efficiency factor B and imbibition % fibre has been used for deriving mill extraction at different imbibition % fibre as indicated above.

![TFH vs Factor B](image)

Fig. 2a—Variation of factor B with cane fibre rate (Mon Trésor).

![Fig. 2b—Variation of factor B with cane fibre rate](image)

Fig. 2b—Variation of factor B with cane fibre rate (Union St Aubin).

![Fig. 3a—Variation in mill extraction with imbibition % fibre](image)

Fig. 3a—Variation in mill extraction with imbibition % fibre (Mon Trésor).

![Fig. 3b—Variation in mill extraction with imbibition % fibre](image)

Fig. 3b—Variation in mill extraction with imbibition % fibre (Union St Aubin).

The net and combined revenues due to a surplus or a shortfall around a datum with an increase in imbibition % fibre are shown in Figures 5a and 5b for MT and USA respectively. The datum imbibition % fibres of MT and USA are respectively 230 and 150. While the price of sugar is assumed to be fixed at Mauritian rupees (MUR) 12,500 per tonne, the price of export electricity varies: for MT MUR 1.1865 per kWh and for USA MUR 1.2500 per kWh.

From Figure 5a it can be observed that MT's revenue derived from electricity decreases with an increase in imbibition % fibre because steam, which would have otherwise been used for producing electricity, is used for evaporating the surplus water added for an increased imbibition % fibre. Revenue from electricity is constant at USA and is independent of imbibition % fibre because at USA there is an excess of exhaust steam which is otherwise condensed in an evaporator when it is not used as process steam (Figure 5b). Since the revenue from electricity relative to the datum is zero, the revenue curve for sugar and that for electricity and sugar coincide.

The revenue curves for sugar and the combined revenue curves show that, for each factory, there is effectively an imbibition % fibre which gives the maximum revenue and would, therefore, be the optimum operating point for the factory concerned. For each factory, the optimum imbibition % fibre differs for different milling conditions. In the case of MT and USA, it is around 210 and 160, respectively.

In this study, although fibre % cane has an influence on extraction, its effect has not been separated from that of imbibition rate to simplify the analysis. Further, only linear correlation for the data has been used since, by visual inspection of the graphs, there seemed to be no other evident correlation.
Fig 5a—Variation of revenue with imbibition rate—Basis: analysis 3/8/99 (Mon Trésor).

Fig. 5b—Variation of revenue with imbibition rate—Basis: mean analysis (Union St Aubin).
Conclusion
The formula derived by Hugot for quantifying total mill extraction of the milling tandem at various imbibition rates is a convenient means for determining corresponding milling extraction given a set of factory conditions. Simulation using Hugot’s formula for determining the effect of imbibition rate on mill extraction, in conjunction with energy balance calculation at different imbibition rates, enables the determination of the optimum imbibition to maximise combined revenue from sugar and electricity. The method used in this study can be easily adapted to specific factory conditions.

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REFERENCES

LE CONTROL DE L’IMBIBITION POUR AUGMENTER LES REVENUS OBTENUS A PARTIR DU SUCRE ET DE LA COGÉNÉRATION

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Résumé

Mots clefs: Extraction, cogénération, énergie, économique, performance.

OPTIMIZACION DE INGRESOS TENIENDO EN CUENTA LA COGENERACION Y LA EXTRACCION DE POL MEDIANTE EL AJUSTE DEL PORCENTAJE DE IMBIBICION

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Resumen
Se usaron los datos de operación obtenidos de dos fábricas para determinar la validez de la fórmula de Hugot que cuantifica la extracción a varias imbibiciones % de fibra para una velocidad de molienda constante. Simultaneamente y mediante un balance de energía se determinó la electricidad producida a diferentes imbibiciones % de fibra. Las ganancias netas y combinadas obtenidas de la extracción de azúcar y electricidad producida se determinaron y fueron puestas en un gráfico versus la imbibición % de fibra. Los resultados muestran que para cada fábrica existe una imbibición% de fibra que rinde una ganancia óptima.

Palabras claves: Extracción en los molinos, azúcar recobrada, cogeneración, energía, economía.