PRIORITISING OPTIONS TO REDUCE THE PROCESS STEAM CONSUMPTION OF RAW SUGAR MILLS

By

B.P. LAVARACK, J.J. HODGSON and R. BROADFOOT
Sugar Research Institute, Mackay, Queensland, Australia
b.lavarack@sri.org.au

KEYWORDS: Cogeneration, Energy, Steam, Bagasse.

Abstract

Low world sugar prices are making it increasingly difficult for raw sugar mills to remain competitive, and many milling companies are embarking on new revenue earning opportunities. In almost all new ventures, the energy from bagasse (as steam or cogenerated electricity) or the fibre itself provides an important basis for generating the additional revenue. Integral to increasing the economic viability of such projects is the need to cost-effectively reduce the steam consumed by the factory for sugar manufacture. The Sugar Research Institute has completed a comprehensive study of numerous options to reduce the process steam consumption of factories, and to determine the financial implications of the different options. Process simulation software for evaporators, pans and heaters were integrated with a basic high pressure steam model. For each process steam efficiency option, the effects on boiler load, fuel consumption, and cogeneration output could be accurately assessed for selected steam conditions at the boiler. The outputs from the integrated process model were directly linked to the financial model. For nominated input conditions, the project determined a prioritised list of technically and economically attractive options for reducing the steam consumption of the factory. The analyses were undertaken for three scenarios which include sale of export electricity, sale of surplus steam or sale of surplus bagasse. This paper describes the development of the integrated models and the results for a base case study. The results show a quintuple station is the preferred evaporator configuration for circumstances where the steam on cane is reduced from current levels of approximately 50% on cane to about 40%. To reduce the steam consumption below this level, a sextuple arrangement is preferred. A quadruple set shows inferior results for all steam on cane values. Options for steam on cane to below 30% were found to be technically feasible for cane factories, but these configurations are not likely to be economically justified.

Introduction

The sustained low price of raw sugar obtained on the world market is impacting on the economics of raw sugar production in Australia and other countries. For raw sugar mills to remain competitive, many sugar producers are investigating value-adding projects for increasing revenues. In most new ventures, the fibre in bagasse or the energy from bagasse (either as steam or cogenerated electricity) is an important component in the value-adding opportunity.

Integral to increasing the economic viability of value-adding projects is the need to cost-effectively reduce the steam consumed by the factory for sugar manufacture. Efficiency modifications to process plant configurations of a raw sugar factory provide surplus low pressure (LP) steam which can be diverted through the condensing stage of a turbogenerator in a cogeneration project, sent to a collocated process plant for heating duties (e.g. to an ethanol distillery or other fermentation plant), or employed as a means of reducing boiler steam load and saving bagasse. This paper investigates the economics and prioritises steam efficiency options for Australian raw sugar factories diversifying into any one of these three scenarios.

Project scope

Previous studies by SRI (Lavarack et al., 2004; Broadfoot, 2001; and Wright, 2000) have identified process plant configurations which provide low steam on cane (SOC) ratios. These include the extensive vapour bleeding options employed by the beet industry to contain fuel costs. The scope of work undertaken for this project has been to:
Investigate numerous process plant modifications and factory operational changes to reduce LP steam consumption, using a typical factory as the ‘Base Case’.

Quantify the reduction in process steam consumption for each option and the subsequent net increase in electricity generation, steam availability or bagasse production.

Consider the impact that each option has on the HP steam cycle, including condensate quantity, quality and temperature and turbine backpressure and extraction pressure effects.

Extend conventional vapour bleeding options to include boiler condensate and demineralised water heating and heat recovery from waste condensate streams.

Investigate the practical limits for a cane factory of the highly efficient options employed by the beet industry.

Establish all capital, operating and maintenance costs (or savings), including effects on internal electricity use, cooling tower loads, station capacities, sugar production and molasses production.

Investigate the economic viability of each efficiency option using a 20-year project financial model;

Develop a prioritised list of the preferred plant configurations for the strongest economic return.

Identify the optimum SOC level for a specified steam efficiency project for cogeneration, collocation of another process requiring steam or the saving of bagasse, based on a given revenue price (e.g. A$/MWh, A$/t steam or A$/t bagasse).

Methodology

A ‘Base Case’ factory comprising a quintuple evaporator set was initially selected to represent a typical Australian raw sugar factory; the base from which all efficiency options were modelled. Plant sizes and operating performance parameters were set, as were industry-accepted limits to the performance of modified or new plant. Performance penalties were also established where efficiency options compromised sugar recovery or throughput (e.g. extended season length resulting from reduced productivity on the pan stage when operating on low pressure vapour).

Many factory process simulations were undertaken, starting with low capital options and progressing through to more expensive, higher steam efficiency configurations. The better performing low-cost options became ‘add-on’ features to more aggressive modifications. Patterns gradually emerged as to which configurations performed best economically. For most vapour bleed configurations, the quintuple effect ‘Base Case’ factory was also modelled as a quadruple and sextuple arrangement.

Efficiency measures which were considered included clarified juice substitution for water e.g. for flocculant dilution, reduction in added maceration and filter water, flashing of condensates to following effects, pressurising the boiler feedwater tank, clarified juice heating by vapour or condensate, mixed juice heating using waste condensate, progressive juice heating using vapour from all effects (including the final vessel), and operating the pan stage on vapour (down to #3 effect). The heating of cogeneration cold streams such as demineralisation feedwater and returning steam turbine generator (STG) condensate, using vapour or waste condensate, was also assessed. An analysis was also done on the ‘reverse clarified juice flow’ concept employed at many beet factories in Europe.

The capital, operating and maintenance costs for each option were linked directly to a financial cash flow model to calculate the price of the revenue stream (i.e. A$/MWh, A$/t steam or A$/t bagasse) required to meet a nominated project internal rate of return (IRR). The project net present value (NPV) was also calculated for a nominated revenue price. The results were then plotted against SOC for all options modelled so that the best performing options could be easily identified for a selected SOC figure. Conversely, the optimum SOC figure that gave the best project return for a range of revenue prices could be easily identified.

Simulation software

The large number of energy efficiency options modelled required the integration of software to simulate juice flows, evaporator and heater operations. This integrated process energy model was linked to a basic HP steam model so that the effects on boiler load, fuel consumption and cogeneration output could be accurately assessed for selected boiler steam conditions. An option to include electric drives in lieu of
turbines for mill and shredder drives was also included. The process model was extended to include plate heat exchangers for a range of heat recovery options, while direct contact juice heater options were also explored.

The operating outputs of the integrated process model were directly linked to the financial model. A comprehensive database of process plant capital costs was compiled and included in the economic model so that all new capital plant items could be selected from a drop-down menu. Maintenance savings were automatically credited to configurations with redundant plant, such as cooling towers.

**Base conditions for study**

The main conditions assumed for the base case are given in Table 1. These conditions would be typical for an Australian sugar factory, but do not represent any particular factory.

<table>
<thead>
<tr>
<th>Process parameter</th>
<th>Nominated value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane rate during continuous operations</td>
<td>600 t/h</td>
</tr>
<tr>
<td>Maceration rate</td>
<td>220 water% fibre</td>
</tr>
<tr>
<td>Fibre on cane</td>
<td>14.0 fibre% cane</td>
</tr>
<tr>
<td>Pan water usage</td>
<td>4.2 water% cane</td>
</tr>
<tr>
<td>Filter water usage</td>
<td>10.0 water% cane</td>
</tr>
<tr>
<td>Miscellaneous water usage</td>
<td>3.3 water% cane</td>
</tr>
<tr>
<td>LP steam saturated temperature</td>
<td>119.9°C</td>
</tr>
<tr>
<td>Clarified juice brix</td>
<td>15.0</td>
</tr>
<tr>
<td>Syrup brix</td>
<td>68.0</td>
</tr>
<tr>
<td>Primary juice temperature range</td>
<td>30.0–77.0°C</td>
</tr>
<tr>
<td>Secondary juice temperature range</td>
<td>75.0–103.0°C</td>
</tr>
<tr>
<td>Clarified juice temperature</td>
<td>97.0°C</td>
</tr>
<tr>
<td>Primary juice% cane</td>
<td>104.0%</td>
</tr>
<tr>
<td>Secondary juice% cane</td>
<td>125.0%</td>
</tr>
<tr>
<td>Clarified juice% cane</td>
<td>110.0%</td>
</tr>
<tr>
<td>Primary heater area</td>
<td>600 m²</td>
</tr>
<tr>
<td>Secondary heater area</td>
<td>900 m²</td>
</tr>
<tr>
<td>Clarified juice heater area</td>
<td>0 m²</td>
</tr>
<tr>
<td>Evaporator heat transfer areas</td>
<td>#1 4700 m²; #2 3400 m²; #3 3400 m²; #4 3400 m²; #5 4000 m².</td>
</tr>
<tr>
<td>Pan steam%liquor solids</td>
<td>93.0%</td>
</tr>
<tr>
<td>Miscellaneous steam % cane</td>
<td>3.0%</td>
</tr>
</tbody>
</table>

All heating duties in the process house are on LP steam with the exception of the primary heater which operates on vapour #1. The overall steam consumption for the base case factory is 51.7% on cane.

Table 2 lists important economic parameters for the study.

<table>
<thead>
<tr>
<th>Economic parameter</th>
<th>Nominated value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project period</td>
<td>20 years</td>
</tr>
<tr>
<td>Operating and maintenance costs</td>
<td>Annual costs which vary between 1% and 4% of the capital cost.</td>
</tr>
<tr>
<td>Electricity price*</td>
<td>A$62 per MWh</td>
</tr>
<tr>
<td>Steam price*</td>
<td>A$10 per tonne</td>
</tr>
<tr>
<td>Bagasse price*</td>
<td>A$15 per tonne</td>
</tr>
<tr>
<td>Inflation</td>
<td>nil</td>
</tr>
<tr>
<td>Tax/depreciation</td>
<td>nil</td>
</tr>
<tr>
<td>Residual plant value</td>
<td>nil</td>
</tr>
<tr>
<td>Season length</td>
<td>23 weeks with 10% lost time</td>
</tr>
<tr>
<td>Discount rate</td>
<td>15.0%</td>
</tr>
</tbody>
</table>

*The net present value (NPV) is calculated assuming the respective prices.
Results and discussion of different process configurations

More than 150 LP steam efficiency options were modelled. However, not all options were cost effective and only the more economically attractive were selected for the comparative analysis.

Low cost options

A group of low cost measures was found to provide good economic returns. These measures include:

(i) substitution of process water with clarified juice;
(ii) clarified juice heater using \#1 vapour;
(iii) pressurised boiler feedwater system (Wright and Joyce, 2001); and
(iv) miscellaneous plant heating using \#1 vapour (in lieu of LP steam).

For cogeneration, the heating of demineralised water and STG condensate with \#2 vapour was found to have high returns and should be included in the group of low cost options.

Vapour bleeding to pans

Vapour bleeding to pans showed inferior economic returns to vapour heating of juice, for steam consumption levels above 42 steam% cane.

A SOC level of 42% to 44% is about the limit for vapour bleeding to juice heaters, using (i) \#3 and \#4 vapour for the primary heaters and (ii) \#1 and \#2 vapour for the secondary heaters. In order to achieve steam consumption levels lower than 42 steam% cane, vapour bleeding to pans is necessary.

The quality of the condensate for boiler feedwater is important for options which employ high pressure boilers.

If LP steam usage needs to be dedicated to the first effect, in order to ensure that high quality condensate is returned to the high pressure boilers, there may be an over-riding reason to employ vapour bleeding to the pans, prior to lower temperature vapour bleeding to juice heaters.

Pre-evaporators

Modelling of a pre-evaporator with a quintuple set of evaporators showed poor project returns. There are no steam economy benefits in installing a pre-evaporator over a larger first effect.

The advantage of installing a pre-evaporator instead of a larger first effect lies in the operational benefit, where any variation in the vapour flow from the pre-evaporator (and associated temperature change) does not impact so heavily on the stability of the remaining effects.

Quintuple versus quadruple versus sextuple evaporator sets

For all three revenue scenarios, the preferred evaporator configuration down to 40 steam% cane is a quintuple set, below which a sextuple arrangement is favoured. The quadruple arrangement shows inferior results across the SOC range.

Juice flow reversal

The beet sugar industry frequently employs a ‘reverse clarified juice flow’ configuration for multiple effect evaporators.

In reverse clarified juice flow, the juice feed enters a pre-evaporator which is heated by a lower effect vapour. The juice from the pre-evaporator then passes to the hotter first effect vessel, while the vapour from the pre-evaporator is dedicated to a process heating duty. Simulations of similar configurations were undertaken.

The results for these options compare poorly against other options and would not be recommended unless extremely low SOC levels (as is common in the beet industry) were being pursued.

Results of economic analysis

Cogeneration scenario

The results from the best performing options for cogeneration are presented in Figure 1 with the power export price set at A$62/MWh.
The best options for cogeneration lie in a band between 48 and 39 steam\% cane. Plots with and without the capital requirements for the associated HP steam plant modifications are included in the figure.

**Surplus steam production scenario**

The results from the preferred options for the production of steam for export to a collocated project are given in Figure 2. A notable difference in the plot for steam production compared to the plot for cogeneration is that there is no peak for the NPV plot (within the range of SOC options investigated), indicating that the returns for selling steam to a collocated process at A$10 per tonne are marginally improved, even at very low SOC values. Of note, the economic returns (NPV) are substantially greater than for cogeneration.
Bagasse production scenario

The preferred options for the production of surplus bagasse are illustrated in Figure 3. The plot is for a sale price for surplus bagasse at A$15 per tonne and shows the peak NPV value is achieved at about 37% SOC.

General comments

For the three scenarios for increased sale prices for the output, the NPV and IRR values are increased and for those cases with peak values for NPV (cogeneration and surplus bagasse), the optimum value for SOC will move to lower values. It is important to realise that these results only apply to LP steam efficiency costs, and assume that HP steam plant can operate at the reduced factory steam loads.

While steam-on-cane figures below 30% are technically feasible in the cane sugar industry, the economic viability of steam efficiency projects is subject to project costs, changes to operating and maintenance costs and the extra revenue generated. In general, SOCs as low as 30% were found to be uneconomic (except perhaps for the sale of surplus steam).

Prioritising options for specific factory sites

The plots for each of the value adding scenarios given in this paper are specific for the base case factory and the revenue price. In general, the prioritisation of options is applicable to most raw cane sugar factories. However, based on SRI's experience of applying these principles to site specific case studies, there are often other critical factors which must be incorporated into the assessments.

These factors include the utilisation of existing boiler plant, guarantees of condensate quality for high pressure boilers, control of plant, minimisation of stoppages when stockpiled bagasse is consumed, combination of revenue options e.g. cogeneration and stockpiling bagasse for out of season export of power.

It has also been found that the sizes of existing evaporator equipment and their configuration have a strong influence on the capital cost of implementing low pressure steam consumption options. It is therefore necessary to undertake the modelling assessments for the site specific circumstances and constraints. SRI has completed several studies of this type for Australian factories. One example is for the cogeneration project for Pioneer Mill in North Queensland, as reported by Lavarack et al. (2004).

Conclusions

While this study was based on a 'typical' sugar factory in Australia, SRI has now developed the tools and knowledge to quickly evaluate site-specific process steam efficiency projects. Results from this work will ensure that the most economically viable solutions are initially identified, followed by a more rigorous assessment of the preferred option(s). The tools developed in the study have been applied to several investigations for Australian factories.
Acknowledgements

SRI would like to thank various sugar mill equipment suppliers for their efforts in supplying capital cost and plant performance information for this study. The funding assistance provided by the Department of State Development of the Queensland Government is acknowledged and appreciated. Funds were also provided from SRI reserves.

REFERENCES


DES OPTIONS POUR REDUIRE LA DEMANDE DE VAPEUR POUR LA FABRICATION EN SUCRERIE

B.P. LAVARACK, J.J. HODGSON et R. BROADFOOT

Sugar Research Institute, Mackay, Queensland, Australia

b.lavarack@sri.org.au

MOTS CLEFS: Cogeneration, Energie, Vapeur, Bagasse.

Résumé

Les sucreries de canne font face à des conditions financières difficiles, et il devient nécessaire de revoir les sources des revenus financiers. Dans presque tous les cas c'est la bagasse, ou la fibre, qui sont considérées ; au départ il faut donc réduire la demande d'énergie de la fabrication pour libérer ces matériels. Le Sugar Research Institute a étudié un grand nombre d'options pour réduire la demande de vapeur vers la fabrication et pour déterminer les effets de ces options sur les coûts à la sucrerie. On a étudié les évaporateurs, les cuites et les réchauffeurs à travers une simulation basée sur l'utilisation de vapeur à haute pression. L'effet de chaque option sur la demande aux chaudières, sur le combustible requis et sur la quantité de cogeneration produite a été étudié ; les résultats sont alors liés à un modèle financier. Le projet donne une liste d'options avec des priorités techniques et financières pour réduire la vapeur de fabrication. Les analyses considèrent trois scénarios : l'exportation d'électricité, la vente de vapeur ou de bagasse. Ce papier discute le développement du model et donne les résultats pour un cas spécifique. Pour réduire la vapeur de 50 à 40% canne l'étude montre que l'évaporation se fait par un quintuple ; une réduction plus forte demande un sextuple. Un quadruple est inférieure dans tous les cas. On montre qu'il est possible de réduire la demande à 30% canne, mais cela n'est plus justifiable économiquement.
ESTABLECIMIENTO DE PRIORIDADES EN LAS OPCIONES PARA REDUCIR EL CONSUMO DE VAPOR DE PROCESO EN LOS MOLINOS DE AZÚCAR CRUDA

B.P. LAVARACK, J.J. HODGSON y R. BROADFOOT
Sugar Research Institute, Mackay, Queensland, Australia
b.lavarack@sri.org.au

PALABRAS CLAVE: Cogeneración, Energía, Vapor, Bagazo.

Resumen

Los precios bajos del azúcar a nivel mundial están haciendo que resulte crecientemente difícil para los molinos de azúcar cruda continuar siendo competitivos, y muchas compañías de molinos están embarcándose en nuevas oportunidades de ingresos. En casi todas las empresas, la energía proveniente del bagazo (como el vapor o la electricidad cogenerada) o la fibra misma proporcionan una base importante para la generación del ingreso adicional. Parte integral de la creciente viabilidad económica de dichos proyectos es la necesidad de reducir el costo efectivo del vapor consumido por la fábrica para la manufactura del azúcar. El Instituto de Investigación del Azúcar ha realizado un estudio amplio sobre las numerosas opciones para reducir el consumo del vapor de proceso en las fábricas, y para determinar las implicaciones financieras de las distintas opciones. Así, se integraron programas de cómputo para la simulación de procesos de evaporadores, tachos y calentadores, con un modelo básico de vapor de proceso de alta presión. Para cada opción de eficiencia del vapor de proceso, se evaluaron con precisión los efectos sobre la carga de la caldera, el consumo del combustible, y el producto de la cogeneración para las condiciones de vapor dadas en la caldera. Los rendimientos del modelo de proceso integrado estuvieron directamente relacionados con el modelo financiero. Para las condiciones de entrada dadas, el proyecto determinó una lista de prioridades de opciones técnica y económicamente atractivas para reducir el consumo de vapor de la fábrica. Los análisis se desarrollaron para tres escenarios que incluyen venta de electricidad de exportación, venta de vapor excedente o venta de bagazo excedente. Esta ponencia describe el desarrollo de los modelos integrados y los resultados para un estudio de caso base. Los resultados muestran que una estación quintuple es la configuración del evaporador preferente para circunstancias en las cuales el vapor de la caña se puede reducir de los niveles actuales de aproximadamente 50% de caña a alrededor del 40%. Para reducir el consumo de vapor por debajo de este nivel, se prefieren un arreglo sémiple. Un arreglo cuádruple muestra resultados inferiores para todo el vapor sobre los valores de la caña. Se encontró que para las fábricas de caña las opciones del vapor de la caña por debajo del 30% eran técnicamente viables, pero que dichas configuraciones no parecen justificarse económicamente.