FACTORY CONCEPTS FOR VERY LOW STEAM DEMAND
AND STATUS OF IMPLEMENTATION

By

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Abstract

THE EXPORT of power from cane sugar factories allows the production of ‘green energy’
and proves nowadays as a substantial source of revenue as well. Looking to the co-
generation potential of the cane sugar industry, the power export is in fact still at a very
early stage. The report gives an overview about concepts and measures that are required
to achieve a low steam demand and high electrical power export for different factory
concepts. The impact of sugar extraction by mills and diffusers as well as the option of
producing refined sugar in an attached refinery is investigated. The factory models
investigated allow steam demands to reduce to the range of 26–34% steam on cane.
Such factory concepts are not theoretical any more but have been implemented and
successfully proven in several plants in India, Brazil and Pakistan in the last five years.
The report gives an overview about the actual achievements.

Introduction

While saving of process steam has not been very attractive for many cane mills in the past,
the situation has turned in the last decade substantially since electrical power can be sold for
reasonable prices, in many cane processing countries, to the national grid or directly to external end
consumers. The carbon credit trade has acted to some extent as a catalyst to accelerate this process
and has proven to be a most welcome add-on to boost the electrical power production of cane sugar
factories. Electrical power prices of 50–60 €/MWh in countries like Brazil and India make power
exports more attractive. The market price for each tonne of carbon dioxide substituted by the
production of electrical power from bagasse is approx. 5–15 €/t CO₂ and this adds to the revenues.

Taking into account that, with well proven technologies, electrical power exports of 100–
125 kWh/t cane are already possible today, the potential to create ‘green energy’ is huge. In the case
where bagasse gasification is applied, even 200 kWh/t cane would be possible in the future (Turn,
1999). Considering sugarcane production in more than 100 countries worldwide with approx. 1800–
2000 sugarcane and bio-fuel (ethanol) factories processing approximately 1558 million t cane/year
(FAOSTAT, 2008), the power production potential amounts to 156–179 TWh/year. In other words,
20 MW power export capacity would have to be installed in each cane processing factory in order
to match the actual potential.

Another trend observed is producing better sugar qualities locally with a tendency to white
(refined) sugar production of less than 45 ICUMSA units in back-end refineries.

This report gives an overview about energy efficient process schemes employed in the cane
sugar industry and typical benchmark numbers that can be achieved.

Base concepts

There are various configurations possible to process sugarcane to sugar. Mill and diffuser
extraction concepts compete, with diffusers gaining more ground on an international basis today.
While in most countries a three-stage crystallisation scheme with an eventually attached back-end refinery is typical, in Brazil usually approximately half of the sucrose in cane is converted to sugar and half to ethanol. A diffuser and mill-based plant concept with and without back-end refinery have been chosen to benchmark the steam demand and the power export. Sub scenarios have been created in order to show, for example, the effect of different imbibition rates. In Table 1 the main input variables for the subsequent calculations are summarised.

### Table 1—Base data for the process calculations.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane crushing rate</td>
<td>10,000 t cane/day</td>
</tr>
<tr>
<td>Effective crop length</td>
<td>180 days</td>
</tr>
<tr>
<td>Sugar content in cane</td>
<td>14%</td>
</tr>
<tr>
<td>Fibre content in cane</td>
<td>14%</td>
</tr>
<tr>
<td>Imbibition rate</td>
<td>35 or 44% on cane</td>
</tr>
<tr>
<td>Bagasse moisture</td>
<td>50%</td>
</tr>
<tr>
<td>Sugar recovery extraction</td>
<td>97 or 98%</td>
</tr>
<tr>
<td>Exhaust steam pressure</td>
<td>240 kPa(a)</td>
</tr>
<tr>
<td>Evaporators</td>
<td>4 or 5 effect Falling film tubular with multistage distributor</td>
</tr>
<tr>
<td>Boiler steam pressure</td>
<td>10,900 kPa(a)</td>
</tr>
<tr>
<td>Boiler steam temperature</td>
<td>535°C</td>
</tr>
<tr>
<td>Sugar colour</td>
<td>&lt; 45 IU in case of the concepts with attached refinery</td>
</tr>
<tr>
<td></td>
<td>350–600 IU in case of the raw sugar factory concepts</td>
</tr>
<tr>
<td>Factory power consumption for:</td>
<td></td>
</tr>
<tr>
<td>Refined sugar production</td>
<td>25 kWh/t cane for diffuser concepts and 30 kWh/t cane for mill extraction concepts</td>
</tr>
<tr>
<td>Raw sugar production</td>
<td>20 kWh/t cane for diffuser concepts and 25 kWh/t cane for mill extraction concepts</td>
</tr>
<tr>
<td>Final molasses purity</td>
<td>30%</td>
</tr>
<tr>
<td>Overall sugar recovery</td>
<td>89.5–90.5%</td>
</tr>
</tbody>
</table>

An important aspect is a very high sugar recovery of 89.5–90.5%. Many sugar factories compromise on this important benchmark figure and there are many factories achieving sugar recovery efficiencies from 80–85% only. For the calculation of the different process models, the ‘Sugars’ program was employed.

### Technologies employed

In the following, the most important technologies considered for the concept evaluation are summarised:

- Diffuser plus dewatering mills or milling tandem (6 mills)
- Recycling of clarifier underflow in case of the diffuser models
- Defecation in the juice purification
- Partly direct contact heaters and plate or platular heaters for liquid/liquid applications
- Optimum usage of heating with condensate
- Falling film evaporators
- Stepwise flashing of condensates by ‘condensate cigars’
- CIP (clean in place) system for heaters and evaporators
- Minimisation of evaporator condenser loss
• Batch pans for seed massecuite and refinery products R1, R2 and R3
• Continuous pans for the raw house operation
• Syrup/molasses wash layer system for A sugar
• Crystal seed technology in the raw house
• High pressure boilers with 109 bar and 535°C
• Extraction/condensing turbo alternators
• Fully electrified drives (no steam turbines)

Apart from the mentioned core technologies, it has been assumed that modern equipment is employed and the factory is well designed having good automation.

Arguments for the selection of diffuser versus milling tandem technology have been summarised by Rein (1995, 1999), Mullapudi (2006) and many other authors. In the subsequent chapters, additional background information about some of the aforementioned technologies is given.

Impact of defecation and sulfitation

For the production of refined white sugar the defecation process is preferred. If sulfitation is applied in the juice purification stage and eventually for syrup sulfitation, the sugar quality in the raw house can be improved from approx. 350–600 IU to 70–100 IU. This is important for factories producing plantation white sugar for local consumption.

There have been fears in the past that sulfated juices are not suitable for the operation of falling film evaporators as a harder and thicker scale formation could be expected on the evaporator heating surfaces.

This cannot be confirmed. Falling film tubular as well as Falling film plate evaporator trains are operating successfully nowadays with either defecation or sulfitation systems in factories in Brazil, India and Pakistan (Avram et al., 2007).

Tube/plate heaters versus direct contact heaters

In order to minimise the process steam demand, indirect and step-wise heating of process flows with tubular or plate heaters is required. However, there are arguments to employ direct contact (DC) heating where applicable because:

1. DC heaters are inexpensive and easy to integrate with low space demand.
2. Allow an approach temperature of 0.5–2 K while tubular or plate heaters require 4-8 K.
3. Almost no cleaning or down time.
5. High load flexibility with minimum performance change.

The juice dilution by injected vapour is of course a drawback of DC heaters. The set-up is crucial as one has to consider that the vapour and the juice system are directly connected and safety measures are required to avoid juice carry over to the condensate system and sugar losses.

The steam on cane demand can be further reduced by 2–3% when only indirect heating with tubular or plate type heaters is employed.

Especially plate heaters require a disciplined and rigid cleaning regime and often do not show the expected performance stated by the suppliers.

For the calculated concepts, direct contact heaters have been considered for raw and limed juice heating as well as clarified juice heating.
It has to be considered that employing DC heaters shifts the requirement for heating surfaces from heaters to the evaporators. The overall investment does not change substantially. It is the operating cost and process performance that favour the DC heaters.

**Evaporator technology**

The most widespread evaporator technology in the cane sugar industry is still the Robert type evaporator with some Kestner applications in selected countries. The process steam demand on cane is limited in these cases to usually 36–40% on cane in the case of raw sugar factories or 45-55% on cane for factories with back-end refineries.

Experience has been gained (Avram et al., 2007, Bhagat, 1996, Journet, 2005, GEA, 2009) in the last 20 years with falling film tubular and later also plate type applications especially in cane sugar mills in Brazil, India and Pakistan with units usually employed in the 1st and 2nd effect (approx. 250–300 units to date). During the past five years, full trains of falling film type evaporators have been introduced.

The authors have been involved in the design of eight plants where exclusively falling film tubular or falling film plate evaporators have been employed. The right evaporator and process engineering design are a crucial aspect here.

The automation of such plants is relatively simple but a well adapted CIP process is required. Good training for local personnel is required to adapt to such new technologies but overall the predicted results have been achieved after an initial learning curve.

Figure 1 displays the k-values (thermal evaporator performance) for Robert, rising film plate, falling film tubular and falling film plate evaporator types (Morgenroth, 2002) in the typical range of applicability in the cane sugar industry.

The k-value is displayed here dependent on the juice viscosity as this parameter is a function of Brix and juice temperature. The plate evaporators show far better efficiencies resulting in less required heating surface and therefore usually less investment.

![Diagram](image-url)

**Fig. 1**—Evaporator performance (k-value) for different viscosities and evaporator types.

On first view, the k-values of Robert and falling film tubular evaporators are not very much different. This is true as long as high temperature differences and high steam consumptions can be accepted.

Figure 2 (Morgenroth, 2002) shows the impact of the specific heat flow density that is correlated to the effective temperature difference. The smaller the specific heat flow, the lower will
be the temperature difference. In the case of rising film evaporators the k-value does not only depend on the juice viscosity. It depends also very much on the available delta-T or specific heat flow density. If the specific heat flow drops below 7 kW/m² heating surface, the thermal performance deteriorates very rapidly.

This is not the case for falling film evaporators where the specific heat flow has practically no impact on the performance. In the case where the overall temperature difference in an evaporation plant is decreased from 125–60°C to 125–90°C, it will not be commercially viable to employ Robert or rising film plate evaporators.

![Fig. 2—Influence of the specific heat flow on the evaporator performance (k-value).](image)

Figure 3 gives an example for a complete falling film tubular evaporation plant recently installed.

![Fig. 3—Five effect falling film evaporation train in AlMoiz, Pakistan.](image)
Discontinuous versus continuous pans and other pan house features

Employing continuous pans in the case of low steam demands is not an absolute prerequisite but can offer further optimisation potential.

Actually, continuous pans show their highest benefit when operated with steam pressures in the calandria of 70–90 kPa(a). In this case, the low massecuite head and use of stirrers allow good and smooth performance. The other benefit is the reduction of vapour demand fluctuations because of the constant load profile. However, well designed batch pans equipped with stirrers and operated with low massecuite heads can also be employed without problems with pressures down to 90 kPa(a) without loss in performance.

A new development is the Spray Continuous Pan (SCP) that follows similar lines in comparison to the BMA type VKT with a vertical arrangement (Verma, 2009). Up to now, 14 units of this type are in operation or under construction (Figure 4).

Continuous pans are considered for the concept evaluation for operation with 4th and 5th effect vapour with pressures from 70–100 kPa(a) depending on the scenario.

A high-grade or ‘white’ molasses wash layer system has been considered for the A batch centrifugal station in the raw sugar house. This technology allows reducing the sugar crystal loss from typically 15–25% to 8–12%, thus reducing the steam and power demand of the process. The white molasses used for this purpose does not dissolve much sugar whereas 1 kg wash water dissolves approximately 3 kg of sugar.

A cooling seed crystal system has been considered as well in order to form a uniform seed material for the raw house products. This is especially important for the C-Mass ICUite seeding as with this technology less high purity material is introduced to the C pans and subsequently lower final molasses purities can be achieved.

Fig. 4—Vertical continuous pans (SCP).
### High pressure boilers and turbines

The increase of boiler pressure (and steam temperature) above 4500 kPa(a) does require an improvement of feed water quality and no sugar traces can be accepted any more. Care has to be taken that condensate with a temperature of approximately 120°C is stored under pressure and continuously analysed for sugar traces by flame photometry (potassium based measurement) or TOC (Total Organic Carbon) based on on-line sensors in order to avoid any potential contamination. Typical boiler pressures vary around 6500 kPa(a)/520°C, 9100 kPa/520°C or 10 900 kPa(a)/535°C. Recently, in India, new boiler installations shifted to 10 900 kPa(a) steam pressure, while the highest pressures in Brazil are 9200 kPa(a) nowadays. The selection is influenced by the availability of experienced local boiler manufacturers as well as on the availability and performance of locally or internationally available steam turbines.

### Results

The results of the calculations for the different process models are displayed in Tables 1 and 2. The process steam requirement lie in a range of 26–34.2% on cane for the different scenarios.

The diffuser models require approximately 2.5–4% steam on cane more than the milling scenarios. The additional process steam demand for refined sugar production varies from 4.2–5.7% process steam on cane.

The specific power export to the electrical grid varies from 100–122 kWh/t cane.

The diffuser based model offers the advantage of approximately 13–14 kWh/t cane more electrical power export compared to the milling tandem based model.

With the diffuser concept scenarios, it is possible to produce approximately 700–1200 t sugar/year more than with the milling concept scenarios. The reason is the return of the clarifier underflow to the diffuser, eliminating the sugar losses in the filter cake. However, the suitability of this arrangement depends on the cleanness of the cane and requires a multi-fuel boiler because of the higher ash content in the bagasse.

<table>
<thead>
<tr>
<th><strong>Table 2— Figures for steam, bagasse and power for diffuser-based models.</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sugar extraction</strong></td>
</tr>
<tr>
<td><strong>Imbibition rate</strong></td>
</tr>
<tr>
<td><strong>Operation time crop</strong></td>
</tr>
<tr>
<td><strong>Total cane crushed</strong></td>
</tr>
<tr>
<td><strong>Process steam on cane (during crop)</strong></td>
</tr>
<tr>
<td><strong>Live steam on cane (crop)</strong></td>
</tr>
<tr>
<td><strong>Total bagasse produced</strong></td>
</tr>
<tr>
<td><strong>Bagasse for stops &amp; losses</strong></td>
</tr>
<tr>
<td><strong>Excess bagasse for off-crop operation</strong></td>
</tr>
<tr>
<td><strong>Annual sugar production (pure sucrose)</strong></td>
</tr>
<tr>
<td><strong>Power production (crop)</strong></td>
</tr>
<tr>
<td><strong>Power consumption (crop)</strong></td>
</tr>
<tr>
<td><strong>Power consumption off crop</strong></td>
</tr>
<tr>
<td><strong>Power export crop</strong></td>
</tr>
<tr>
<td><strong>Power production off-crop</strong></td>
</tr>
<tr>
<td><strong>Power export off-crop</strong></td>
</tr>
<tr>
<td><strong>Total annual power export</strong></td>
</tr>
<tr>
<td><strong>Specific total power export</strong></td>
</tr>
</tbody>
</table>
Table 3—Figures for steam, bagasse and power for milling tandem based models.

<table>
<thead>
<tr>
<th></th>
<th>Scenario 4 Mills (refined sugar)</th>
<th>Scenario 5 Mills (refined sugar)</th>
<th>Scenario 6 Mills (raw sugar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar extraction</td>
<td>%</td>
<td>98</td>
<td>97</td>
</tr>
<tr>
<td>Imbibition rate</td>
<td>% o.c.</td>
<td>44</td>
<td>35</td>
</tr>
<tr>
<td>Operation time crop</td>
<td>days</td>
<td>180</td>
<td>180</td>
</tr>
<tr>
<td>Total cane crushed</td>
<td>t</td>
<td>1 800 000</td>
<td>1 800 000</td>
</tr>
<tr>
<td>Operation time off crop</td>
<td>days</td>
<td>140</td>
<td>140</td>
</tr>
<tr>
<td>Process steam on cane</td>
<td>%</td>
<td>31.7</td>
<td>29.4</td>
</tr>
<tr>
<td>(during crop)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Live steam on cane (crop)</td>
<td>%</td>
<td>36.8</td>
<td>34.5</td>
</tr>
<tr>
<td>Total bagasse produced</td>
<td>t</td>
<td>523 454</td>
<td>529 330</td>
</tr>
<tr>
<td>Bagasse for stops &amp; losses &amp;</td>
<td>t</td>
<td>57 968</td>
<td>58 693</td>
</tr>
<tr>
<td>bagacillo</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excess bagasse for off-crop</td>
<td>t</td>
<td>171 420</td>
<td>194 534</td>
</tr>
<tr>
<td>operation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual sugar production (pure</td>
<td>t</td>
<td>226 860</td>
<td>224 836</td>
</tr>
<tr>
<td>sucrose)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power production (crop)</td>
<td>MW</td>
<td>31.61</td>
<td>29.72</td>
</tr>
<tr>
<td>Power consumption (crop)</td>
<td>MW</td>
<td>12.5</td>
<td>12.5</td>
</tr>
<tr>
<td>Power consumption off crop</td>
<td>MW</td>
<td>~ 2</td>
<td>~ 2</td>
</tr>
<tr>
<td>Power export (crop)</td>
<td>MWh</td>
<td>82 538</td>
<td>74 390</td>
</tr>
<tr>
<td>Power production off-crop</td>
<td>MW</td>
<td>31.05</td>
<td>35.17</td>
</tr>
<tr>
<td>Power export off-crop</td>
<td>MWh</td>
<td>97 601</td>
<td>111 465</td>
</tr>
<tr>
<td>Total annual power export</td>
<td>MWh</td>
<td>180 139</td>
<td>185 855</td>
</tr>
<tr>
<td>Specific total power export</td>
<td>kWh/t cane</td>
<td>100</td>
<td>103</td>
</tr>
</tbody>
</table>

The imbibition rate was varied from 35–44% on cane resulting in a difference in sucrose extraction rate between 97 and 98%. The power export is affected only by 2–3 kWh/t cane and this shows clearly that usually it is more economic to improve the sugar recovery instead of compromising on the imbibition rate. However, this requires of course sufficient evaporator capacity.

An amount of approximately 5% of the available bagasse has been considered for starts/stops and steam losses. This bagasse can also be partly used for power production but this has not been considered here.

Approx. 1.7% on cane bagacillo has been considered to be lost with the filter mud. In the case of very good cane qualities, the bagacillo amount can drop to less than 0.8% on cane. Often, cane trash is burnt in modern multi fuel boilers today in addition to bagasse.

This can add substantially to the power production and should always be considered for a power plant concept. The evaporation operation scheme for Scenario 4 is displayed as an example in Figure 5.
Fig. 5—Evaporation plant operation Scenario 4.
One of the most important differences between a conventional evaporation set-up and the given scenarios is the small effective delta-T with special regard to the last two effects. It has been stated in the past that the higher temperatures in the last effects could cause high sugar losses or colour formation.

Practical experience has shown that this is not the case and supports the known facts of slower sucrose degradation and colour formation (Vukov, 1965; Vukov and Patkai, 1981) in the case of juice temperatures below 110°C.

The juice residence times in a falling film evaporation plant are approx. 25–35 minutes compared to Robert-based trains where often more than 60 minutes residence times can be observed (Morgenroth, 2002). This allows operation at slightly higher temperatures in the initial effects that are more sensitive concerning sugar losses.

There are cases where an investment into high pressure boilers might not be viable. However, bagasse itself is nowadays a valuable product that can be sold for good prices. Therefore, it makes sense to optimise the process.

Conclusions

A steam on cane demand from 26–34% steam on cane (260–340 kg steam/t cane) can be considered nowadays as a benchmark for a modern cane sugar factory supplying also ‘green power’ to the electrical grid. Electrical power exports of 100–120 kWh/t cane to the power grid can be considered as technically and economically feasible.

It might be assumed that a modern factory concept requires higher investment cost. In our experience, this has not been proven as the reduction in steam demand—compared to conventional designs—of approx. 20% on cane or ~40% in total reduces the investment in boilers and turbines substantially allowing additional investment in other areas.

First experience has been gained with such innovative designs in a few mills in Brazil, India and Pakistan and especially the success of the falling film evaporator technology has been proven very well under quite different operating conditions.

REFERENCES


CONCEPTS POURUNE TRÈS FAIBLE DEMANDE DE VAPEUR 
À LA SUCRERIE ET L'ÉVOLUTION DE SON IMPLEMENTATION

Par

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MOTS-CLEFS: Cogénération, l'Efficacité de la Vapeur, Normes d’Energie.

Résumé
L'EXPORTATION d’énergie des usines de canne à sucre permet la production ‘d’énergie verte’ et s'avère aujourd'hui comme une source importante de revenu. En vue du potentiel de cogénération de l'industrie, l'exportation d'énergie est en fait à un stade très précoce. Ce rapport donne un aperçu sur les concepts et les mesures qui sont nécessaires pour obtenir une faible demande de vapeur et une forte exportation de puissance électrique avec des usines différentes. L'impact de l'extraction aux moulins ou avec une diffusion ainsi que l'option de production du sucre raffiné dans une raffinerie attachée à la sucrerie sont étudiés. Les modèles étudiés permettent de réduire la demande de vapeur vers une plage de 26–34% sur la canne. Ces concepts ne sont plus théoriques, mais ont été mis en œuvre et éprouvées avec succès dans plusieurs sucreries en Inde, au Brésil et au Pakistan au cours des cinq dernières années. Le rapport donne un aperçu des résultats obtenus.

CONCEPTOS PARA UNA BAJA DEMANDA DE VAPOR 
EN FÁBRICA Y ESTADO DE IMPLEMENTACIÓN

Por

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PALABRAS CLAVE: Cogeneración, Eficiencia Energética, Vapor, Benchmarking

Resumen
LA EXPORTACIÓN de energía eléctrica desde los ingenios cañeros permite la producción de ‘energía verde’ y se manifiesta también como una fuente sustancial de rentabilidad. Observando el potencial de cogeneración de industria de la caña, la exportación de energía eléctrica se encuentra aún en una etapa muy primaria. Este trabajo presenta un repaso sobre conceptos y medidas que se requieren para lograr una baja demanda de vapor y alta capacidad de cogeneración para diferentes conceptos de fábrica. Se investiga el impacto de la extracción con molinos y difusores también como la opción de producir azúcar refinado en una refinería anexa. Los modelos de fábricas investigados permiten demandas de vapor %caña de 26–34%. Tales conceptos de fábrica no son teóricos ya y han sido probados exitosamente en plantas de India, Brasil y Pakistán en los últimos cinco años. Se presenta un reporte de los logros reales alcanzados.