NEW DESIGN CONTINUOUS VACUUM PAN FOR THE INDIAN SUGAR INDUSTRY—TRIVENI SRI MAKE

By

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Abstract

Triveni Engineering and Industries Ltd (India) and Sugar Research Institute (Australia) jointly developed a new design of a continuous pan for the Indian sugar industry. The first installed pan of 120 m³ massecuite volume was commissioned towards the end of the 1999 season. This paper describes the features of the design and automation and presents results of the performance of the pan on the B massecuite duty. The pan operates on vapour 2, or a combination of vapour 1 and vapour 2, and produces an excellent quality B massecuite at the design rate of 55 to 60 t/h.

Introduction

Sugar mills in India are expanding crushing capacity and seeking to adopt procedures and equipment which minimise steam and power consumption, provide economies of plant space, and reduce sucrose losses. Co-generation of power is being increasingly adopted with emphasis on minimising process steam consumption by using low-pressure vapours from the evaporator system, i.e. bleeding from later effects and thus minimising the heat loss to condensers.

Continuous pans can have a large impact on reducing the total low-pressure steam consumption of the factory and so influence the factory’s steam balance, total steam demand, bagasse usage in the factory’s boilers and hence surplus bagasse quantity. To fully assess the energy efficiency of continuous pans, several factors must be taken into account including:

1. Vapour consumption during normal production to provide the required evaporation rate.
2. Vapour consumption associated with idling of continuous pans and during other non-productive procedures such as boiling out.
3. Additional quantities of massecuite to be boiled if excessive crystal dissolution occurs at the centrifugal station.
4. Electrical consumption of equipment such as pump drives and mechanical stirrers if fitted.

Continuous pans of various designs, employing horizontal and vertical tubes that use vapours from the vapour cell, first or second evaporator bodies are currently installed in India and are used for boiling high-grade and low-grade massecuites. From observations on the performance and levels of automation of the pans currently installed, it was determined that there was the need in the Indian sugar industry for the design of a continuous pan which could operate efficiently on low-pressure vapours, achieve strong exhaustion performance and produce massecuite of good purging qualities.

Triveni Engineering and Industries Ltd (India), in association with Sugar Research Institute (Australia), jointly designed a continuous vacuum pan of modular construction having a capacity of 55 to 60 t/h of B massecuite. The pan was installed at Khatauli Sugar Mill during the final stages of the 1998–1999 season and has operated throughout the 1999–2000 season, producing all the B massecuite of the factory.

This paper discusses the new continuous pan design developed by Triveni-SRI and presents the results of performance trials. Close attention is given to the energy efficiency of the design.

Specification of the pan

The Triveni-SRI pan at Khatauli Mill has a capacity of 120 m³ for B massecuite production at the design rate of 55–60 t/h. The specification of the B massecuite duty is:

**B seed:**
- Rate: 15 t/h;
- Purity: 73 to 74 (apparent purity);
- Mean crystal size: 0.15 mm.

**B massecuite:**
- Purity: 73 (apparent purity);
- Crystal content on massecuite: greater than 40%;
- Mean crystal size: 0.28 mm.

**Feed molasses:**
- A heavy: (73 apparent purity);
- C light: (70 apparent purity).

The pan is of horizontal design with vertical stainless steel tubes (AISI 304) expanded into mild steel tube plates of 32 mm thickness. The tube specification is 102 mm OD of 16 SWG (1.6 mm wall thickness) and 900 mm length. The pan is constructed as three separate modules (with a separate calandria in each module) and includes 12 compartments (cells). The cell volumes are sized to increase progressively from the seed entry end to the product end (Broadfoot, 1992). Computer modeling was undertaken for the nominated duty to ascertain the appropriate number of cells, individual cell volumes, evaporation rates and molasses feed rates. This information was used for sizing the pan itself and also for sizing pipework and

**KEYWORDS:** Continuous Pan, Design, Vapour Consumption, Exhaustion.
control valves. SRI developed software specifically for the design to determine the dimensions and layout of the pan.

Table 1 provides details of the modules, cell sizes, number of tubes and heating surface areas for the pan.

The pan provides an overall heating surface area/volume ratio of 8.65/m and is designed to operate on vapour 2 from the semi-Kestner or vapour from the vapour cell (design saturated vapour temperature of 103°C).

Table 1—Details of the 120 m³ Triveni-SRI continuous pan installed at Khatauli factory.

<table>
<thead>
<tr>
<th>Module</th>
<th>Cell number</th>
<th>Cell volume, m³</th>
<th>Number of tubes</th>
<th>Heating surface area*, m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>2.8</td>
<td>88</td>
<td>23.2</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>2.8</td>
<td>88</td>
<td>23.2</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>4.0</td>
<td>132</td>
<td>34.8</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>8.0</td>
<td>264</td>
<td>69.6</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>9.4</td>
<td>294</td>
<td>77.5</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>11.0</td>
<td>346</td>
<td>91.2</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>12.0</td>
<td>376</td>
<td>99.2</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>12.0</td>
<td>430</td>
<td>113.4</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
<td>14.0</td>
<td>466</td>
<td>122.9</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>14.0</td>
<td>466</td>
<td>122.9</td>
</tr>
<tr>
<td>11</td>
<td>11</td>
<td>14.0</td>
<td>478</td>
<td>126.1</td>
</tr>
<tr>
<td>12</td>
<td>12</td>
<td>16.0</td>
<td>509</td>
<td>134.0</td>
</tr>
<tr>
<td>Total: 3</td>
<td>12</td>
<td>120.0</td>
<td>3938</td>
<td>1038.0</td>
</tr>
</tbody>
</table>

*Heating surface area based on the mean diameter of the tubes and the length of tubes between the inside faces of the tube plates.

Volume based on a nominal boiling level of 400 mm above the top tube plate.

General observations on the performance of the pan

The pan produces very good quality B massecuite of high brix and high crystal content (typically 45% crystal content on solids) and with crystals of very uniform size distribution.

The pan typically operates for 22 to 25 days between boilouts and, during this period, maintains the production rate and good quality product massecuite. No accumulation of settled massecuite has been observed in any section of the pan. There is a complete absence of lumps in the product massecuite and no blocking of tubes has occurred. Both these problems are commonly experienced in other designs of continuous pans in India.

Salient features of the pan

Massecuite transfer arrangements

Massecuite transfer from cell to cell is by underflow except at a module division where the massecuite flows through a valve located in the downtake close to the tube plate level. The valves at the module divisions are fully open during normal operation but can be closed for startup operations, boilouts etc. The product massecuite overflows an adjustable weir pipe mounted on the centreline of the pan, on the end wall of module 3. The product massecuite discharges into a sealed section of a receiver from where it is pumped to the vertical crystallisers.

Circulation of massecuite

In practice, for effective utilisation of the pan capacity, high supersaturation should be maintained consistently in all cells of the pan, without causing nucleation. To achieve this objective, a strong circulation movement of the massecuite is the primary requirement as this achieves uniform supersaturation conditions throughout the whole circulation path within each cell. The pan is so designed that there is a strong rolling circulation, which is assisted by a narrow calandria (i.e. short flow path across the calandria), and a smooth transfer of massecuite through the downtake to the underside of the calandria. The boiling level is selected at about 400 mm above the top tube plate to maximise the rolling action. The circulation path of the pan is designed to avoid any settling of crystals or high brix massecuite.

Steam/vapour entry

A separate steam/vapour entry connection is provided in each module to a position near the centre of each module. This ensures that there is a short distance for vapour to flow from the entry to the extremities of the calandria. This arrangement provides uniform distribution of vapour throughout the calandria. The provision of separate vapour entries to the individual modules allows flexibility in choosing the source of vapour for boiling in the individual modules and allows separate vapour flow rates to be set to match the evaporation requirement for the module.

Hydrostatic head

The maximum height of massecuite within the pan is two metres (i.e. from the base of the pan to the boiling level). This same height exists for the high brix pan discharge massecuite. The effect of hydrostatic head in the continuous pan is much less than for a batch pan owing to (1) the much lower height of massecuite in the continuous pan compared with a batch pan, particularly for the high brix pan discharge massecuite, and (2) the much stronger circulation movement in the continuous pan.

Jigger steam

There is provision for jigger steam addition (of the same vapour supply as used in the calandrias) to the underside of each cell and to the underside of each inter-cell opening. Jigger steam is normally only used on restarting the pan or in cell 12 to assist the circulation of the high brix massecuite.

Average heating vapour demand

The total condensate flow rate from the three modules was measured by magnetic flowmeter and cross-checked by collecting the condensate over a timed interval into a receiver.

The massecuite production rate for the pan was determined by mass balance calculations by measuring the flow rates of A heavy and C light molasses feed, the consumption rate of B seed and the brix of each of the streams. The calculated values for vapour consumption (tonnes) per tonne massecuite
produced typically ranged between 0.25 and 0.27 (average 0.26). These values compare extremely favourably with batch pan demands of 0.50 to 0.55 for the B massecuite duty and more usual vapour demands of other continuous pans of 0.3–0.4. The Triveni-SRI pan has proven to be very economical in terms of vapour consumption.

Mass balance calculations, based on the simulation data for the design of the pan, show that the minimum vapour consumption for the pan at the design rate is 0.24 tonnes per tonne of massecuite produced. In practice, when operating at the design rate, movement water is added only to cell 12 (and possibly a small amount to cell 11) of the pan. The very low vapour usage of the pan is attributed, at least in part, to the inherently good circulation movement and the ability to operate effectively without the excessive addition of balancing water.

**High volumetric efficiency**

Continuous pans provide longer residence times for growth of the crystals than do batch pans of the same process volume on the same duty. The relative increase in crystal residence time is termed the volumetric efficiency. Based on the simulations for the pan at the design rate and growing the seed crystals from a mean size of 0.15 mm to product crystals with mean size of 0.29 mm, the sum of the average residence time for the crystals in each of the cells is 4.48 hours. At the design production rate of 56 t/h, the nominal residence time in the pan (calculated from the massecuite volume in the pan/volumetric production rate) is 3.1 h and the volumetric efficiency is 1.45. This means that, for the same residence time for crystals in the pan, a batch pan of 45% greater volume would need to be installed.

**Selection of the number of cells and the individual cell volumes**

Computer modeling was undertaken by SRI to determine the number of cells and the volume of the individual cells. The simulations are based on the assumption that each cell behaves as a well-mixed cell. The analysis includes allowance for the size dispersion effects which occur for the growth of sugar crystals. Approximately, the arrangement of cells which produces a product of narrow size spread requires that cells of small volume are provided at the seed entry and there is a progressive increase in cell volume from the seed to the product end. The cell volumes included in the pan are shown in Table 1. The pan at Khatauli factory has 12 cells in total. This is a relatively large number and was chosen because it was important to produce B massecuite of excellent purging qualities. It was therefore important that the size distribution of the crystals in the product massecuite was narrowly spread.

The evaluation trials included detailed assessments of the crystal size distribution of proof samples from each of the cells. These measurements involved measuring the length of individual crystals through a microscope with an embedded scale. A total of seven full series of measurements was undertaken and these results are plotted in Figure 1. The results show a nearly linear increase in mean size of the crystals (number mean based on crystal length). For a normal size distribution of the crystals the minimum spread of crystal sizes is expected to be produced when the increase in crystal size in each cell is approximately equal (Broadfoot, 1980). The results shown in Figure 1 indicate that the continuous pan is achieving close to equal increments of growth in each cell.

The average coefficient of variation of the sizes of crystals in the product massecuite was determined to be 0.32 (usual range 0.29 to 0.36). This demonstrates that a very narrow spread of sizes was achieved in the product massecuite. The massecuites were subsequently processed through vertical crystallisers and showed good purging performance at the B centrifugals.

**Automation**

The pan is equipped with comprehensive automation and includes the following control loops:
- Conductivity control in each cell.
- Brix control in the molasses conditioners for both the A heavy and C light molasses.
- Level control in the conditioned molasses transfer tanks.
- Steam flow control to each of the three modules.
- Seed rate control by selection of the pump speed.

In addition, the rates of molasses boil-on for the two molasses streams are measured by magnetic flowmeters and displayed in the control room. The temperature of the vapour supply is also displayed. The massecuite level in the pan is controlled by manually setting the position of the outflow weir on the final cell. The vacuum on the head space of the pan is set by manual adjustment of the injection water valve to the condenser.

The massecuite conductivity measurement for each cell is undertaken using Triveni-SRI radio frequency probes based on the design of the SRI WPR transducer. These conductivity transducers are specifically designed for use in continuous pans. They do not need to be removed for cleaning for the whole period between boilouts of the pan.

The automation proved to be very reliable and simplified the operation and supervision of the pan. Close attention is given to selecting the appropriate production rate for the pan to ensure steady operations can be maintained, without the need to idle the pan unnecessarily due to lack of molasses supply.

**Exhaustion of product massecuite**

The seed for this pan is boiled separately in a batch pan and the grain size is maintained between 0.12–0.14 mm. This seed is metered into the continuous pan at the ratio of about 25% of the product massecuite rate to obtain product crystals of size about 0.28 mm.

The purity difference between the B massecuite and the nutsch mother molasses sample obtained from the product massecuite was consistently in the range 21.5–23 units. Occasionally, the purity difference in
Fig. 1—Development of crystal mean size through the cells of the pan.
Fig. 2—Typical values of massecuite brix in the different cells of the pan.
the product massecuite was 24 units. The purity of the nutsch mother molasses in the product massecuite from the pan was typically between 49.5 and 50.5. These results are for B massecuites at Khatauli factory which are about 73 purity. The crystal content in the product massecuite averages greater than 45% on solids (as determined from the purities of the massecuite and nutsch molasses). It is likely that B massecuite of purity around 70 (more usual Indian practice) would produce a purity difference in the product massecuite of 24 or greater on a consistent basis.

The production of well-exhausted massecuite requires tight control on the set point values of the conductivity control of the individual cells. Massecuite samples were obtained from the proof sampler on each cell for 10 series of trials conducted on different days. The average brix of the massecuite in each cell is shown in Figure 2. The brix measurements were determined by the spindle brix method based on 1:10 dilution. The massecuite brix shows a slight upward trend for cells 1 to 7, before rising more steeply in the latter cells of the pan. The reduction in operating brix in cell 6 was necessary to ensure uninterrupted massecuite flow was achieved through the inter-module valve. The cause of this problem has been determined and corrections implemented. The product massecuite is typically at 97.5 to 98.0 brix. This brix profile through the pan has been found to provide good exhaustion performance.

For operation at the design rate, A heavy molasses is fed to cells 1 to 8; C light molasses to cells 9 and 10 with perhaps a small amount to cell 11, and movement water to cells 11 and 12.

**Vapour flowrates to individual modules**

The condensate flow rate from an individual module was measured by diverting the condensate flow to an isolated drain over a measured time interval. The average condensate rates and calculated values of heat transfer coefficients are given in Table 2. The heat transfer coefficient values are based on a calandria pressure of 5 kPag and massecuite boiling temperatures of 63 °C, 64 °C and 65 °C in modules 1, 2 and 3 respectively.

<table>
<thead>
<tr>
<th>Module</th>
<th>Condensate flow rate (tonnes/h)</th>
<th>Specific evaporation rate (kg/m²)</th>
<th>Heat transfer coefficient, W/m²/K</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.23</td>
<td>22.6</td>
<td>368</td>
</tr>
<tr>
<td>2</td>
<td>4.23</td>
<td>12.6</td>
<td>211</td>
</tr>
<tr>
<td>3</td>
<td>3.12</td>
<td>8.2</td>
<td>141</td>
</tr>
</tbody>
</table>

* Based on the heating surface area calculated from the mean diameter of the tube and the length of the tube between the inside faces of the tube plates.

The B massecuite duty as processed in Indian factories, i.e. reasonably high purity massecuite with very large crystal surface area (having high crystal content and small mean crystal size), requires a high evaporation rate to maintain a high operating supersaturation and to maximise the crystal growth rate. The B massecuite production duty is evaporation limited in the first half of the pan. Hence the achievement of a high evaporation rate (refer Table 2) in the first module is important as this increases directly the production rate of the pan. The ability to be able to set different evaporation rates in different sections of the pan is an important benefit of the modular design.

There is merit, therefore, from the point of view of maximising productivity, in supplying vapour 1 to the first module of the continuous B pan instead of using vapour 2. The decision is one based on the trade off of steam economy (vapour 2 versus vapour 1 on module 1) versus an increase in productivity for the pan. Khatauli factory elected to supply vapour 1 to module 1. The ability to be able to source different vapour supplies to the different modules is one of the major advantages of the modular design.

**Separate module (calandria) system**

In addition to the already mentioned advantages of the separate module design, other benefits are demonstrated through:

(i) Simpler operating procedures during starting of the pan, viz. each of the modules can be started successively rather than simultaneously. This procedure allows the pan to be brought on-line more easily and as soon as sufficient molasses supply is available to commence operations in module 1.

(ii) More rapid liquidation of the pan. All the modules are provided with separate arrangements for liquidation. This substantially reduces the time taken for boilout operations compared with a pan comprising a single calandria and massecuite space.

**Conclusions**

The Triveni-SRI continuous pan has fulfilled all the design requirements and produces an excellent quality B massecuite of high brix, high crystal content and narrow crystal size distribution. The design rate for the pan of 55 to 60 t/h is consistently achieved. The pan maintains its production and quality performance for 22 to 25 days between boilouts. The pan operates on vapour 1 and vapour 2 and consumes only about 0.26 tonnes vapour per tonne massecuite produced. This is only marginally above the theoretical nett evaporation requirement for the production duty and so provides major steam savings for the factory.

**Acknowledgments**

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REFERENCES


UNE NOUVELLE CUITÉ CONTINUE POUR L’INDUSTRIE SUCRİÈRE DE L’INDE

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Résumé

Triveni Engineering and Industries, de l’Inde et le Sugar Research Institute de l’Australie, ont ensemble développé une nouvelle cuite continue, pour les sucreries de l’Inde. La première unité commerciale de 120 m³ a été installée à la fin de la campagne de 1999. Le papier donne des détails sur l’appareil, son automation et les résultats obtenus avec de la massecuite B. La cuite se sert de la vapeur 2 ou d’une combinaison V1/V2 pour produire une excellente massecuite B, a un taux de production de 55 a 60 T/hr.

Mots clefs: Cuite continue, consomation de vapeur, épuisement.

NUEVO DISEÑO DE “TACHO” CONTINUO PARA LA INDUSTRIA AZUCARERA INDIA TRIVENI SRI MAKE

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Resumen

Triveni Engineering & Industries (LTD) (India) y Sugar Research Institute (Australia) conjuntamente, desarrollaron un nuevo diseño de tachos continuos para la industria azucarera en la India. El primer tacho de 120 m3 de masa cocida fue comisionado hacia finales de la zafra de 1999. Esta presentación describe los pormenores del diseño y automatización del mismo, así como los resultados del tacho sobre la masa cocida “B”. El tacho opera con vapor 2, o una combinación de vapor 1 y 2, y produce una masa cocida “B” de excelente calidad a una rata diseñada entre 55 y 60 T/H.

Palabras claves: Tacho continuo, diseño, consumo de vapor, agotamiento.