DESIGN AND OPERATING CRITERIA FOR MAXIMISING THE BENEFIT OF CONTINUOUS VACUUM PANS

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Abstract
CONTINUOUS vacuum pans provide significant advantages in achieving more effective use of installed volumetric capacity than batch pans. Other advantages are reduced supervision, benefits to steam economy and consistency in the composition of the product massecuite. However, in order to maximise the benefits, continuous pans must be operated at high sucrose deposition rates and be able to minimise the effects of any shortcomings such as time off line for cleaning. The paper discusses several important design and operating criteria for maximising the benefits of continuous pans to overall factory operation. Data are presented from operating continuous pans to highlight the importance of these criteria. Such data include circulation velocity measurements for the massecuite flow, residence time distribution data, massecuite exhaustion and crystal quality data. Consideration is given to design changes for future installations of continuous pans and ways to minimise the effects of downtime.

Introduction
Continuous vacuum pans achieve more effective use of the installed volumetric capacity than batch pans. This benefit, coupled with other advantages of improved exhaustion performance, consistent operation, reduced supervision by operators and reduced steam consumption makes continuous vacuum pans an economically attractive proposition for raw sugar crystallisation.

However, there are potential pitfalls in the design and operation which must be avoided if the full benefits are to be achieved.

Current installations of continuous pans in Australian factories
Continuous vacuum pans are employed in 13 of the 28 sugar factories in Australia and are used for all massecuite production duties, as specified in Table 1.

Table 1—Description of the massecuite production conditions in Australian sugar factories.

<table>
<thead>
<tr>
<th>Duty</th>
<th>Massecuite purity</th>
<th>Seed crystal size, mm</th>
<th>Product crystal size, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>A massecuite</td>
<td>85–90</td>
<td>0.60</td>
<td>0.90</td>
</tr>
<tr>
<td>B massecuite</td>
<td>80–84</td>
<td>0.60</td>
<td>0.85</td>
</tr>
<tr>
<td>High grade seed</td>
<td>88–90</td>
<td>0.35</td>
<td>0.60</td>
</tr>
<tr>
<td>C massecuite</td>
<td>64–68</td>
<td>0.18</td>
<td>0.30</td>
</tr>
</tbody>
</table>

The paper presents data from SRI continuous pans operating in Australian factories to demonstrate the magnitude of performance parameters.

Criteria for a successful design of continuous pan
- Successful and cost effective implementation of continuous pans requires that several criteria are fulfilled. These include:
  - Large increase in crystal mean size from seed to product massecuite. This improves the volumetric efficiency of the design and hence the cost effectiveness compared to a batch pan.
Narrow size distribution in the crystal product so that good purging performance is achieved at the centrifugals, and the extent of sugar dissolution by washing is reduced.

High crystal growth rates without the formation of fine grain to ensure that high productivity is achieved.

Good exhaustion performance through the production of massecuites of high brix and high crystal content.

Ability to operate effectively for a wide range of massecuite production rates.

Operation with minimal steam/vapour consumption and the ability to use low pressure vapours, thus allowing improved steam efficiency for the factory.

Use of a simple and effective control scheme which ensures high productivities can be consistently maintained.

Minimal supervision required by the operators.

Ability to operate the pan at the design specification for long periods between cleaning programs.

Use of simple and rapid procedures for pan start-up, shutdown and boilout operations.

In addition to the above list of criteria, the capital cost of the pan installation must be acceptably low.

**Volumetric efficiency and crystal size distribution in continuous pans**

The crystal size distribution (CSD) in the product massecuite is influenced by the crystal size distribution of the seed massecuite, the number and volume of the cells in the continuous pan, the circulation characteristic of the pan, crystal growth rates in the individual cells, growth rate variations due to size dispersion effects, and control procedures for regulating supersaturation.

The capital cost advantage of continuous pans over batch pans is increased in circumstances where a larger increase in the mean size of the crystals, from seed to product, is achieved (Broadfoot, 1992).

This is because the mean residence time for the crystals in the continuous pan is much larger than the nominal residence time (i.e. the residence time equivalent to the massecuite volume held in the pan divided by the volumetric production rate).

The relative increase in the mean crystal residence time compared to the nominal residence time is termed the 'volumetric efficiency'. Values of volumetric efficiency typically range from 1.3 to 1.7, indicating that the continuous pan is 30% to 70% more effective in usage of installed volume than a batch pan on the same boiling duty.

In practice, further efficiencies are achieved for continuous pans over batch pans by the avoidance of the non-productive turnaround time of batch pans between strikes.

Increased economic benefit is obtained from continuous pans which operate with high volumetric efficiency. However, very large increases in mean crystal size will commonly result in a widely spread size distribution in the product massecuite, to the detriment of purging performance at the fugals.

Care is needed to design continuous pans which produce a narrow csd but still have a high volumetric efficiency. While some compromise is necessary, there are two main design procedures available to achieve this.

1. **Use smaller cells in the seed entry end of the continuous pan.** SRI models show that the cell size should increase progressively from the seed to the product end of the pan (Broadfoot, 1980; Broadfoot, 1992). All continuous pans in Australia employ this feature. It is noted that FCB continuous pan designs have adopted this procedure also (Journet, 1994).

2. **Adopt procedures such as employing a long flow path for the crystals to pass from the seed entry to the product outflow** (Betancourt et al., 1989; McDougall and Wallace, 1982) or installing a large number of cells in order to provide a narrow spread of residence times for the crystals in the pan (Rein et al., 1985).

The residence time distribution for the 10 cell continuous A pan at Tully Mill is shown in Figure 1. A match of the data to a mixed tanks-in-series model shows that the residence time distribution approximates 15 well-mixed tanks of equal residence time.

The approximation to a large number of mixed tanks in series indicates the flow behaviour is approaching ideal plug flow. The residence time distribution demonstrates that no short-circuiting of the massecuite is occurring and there is no evidence of stagnant or slow moving regions.
The recycle (boilback) of molasses from the fugal will affect the residual lithium concentration measured towards the end of the test.

Fig. 1—Lithium concentration in the product massecuite as a function of the sampling time (source: Broadfoot et al., 2004).

By way of illustration of the CSD which can be produced in continuous pans, Figure 2 shows photographs of the crystals at cell 1 and the product A massecuite for the SRI continuous A massecuite pan at Tully Mill. No dilution of the massecuite was undertaken prior to photographing the samples.

The photographs show:
- the large increase in mean size of the crystals, and narrowing of the size distribution with growth in the pan; and
- the high crystal content, large mean size and narrow distribution of the crystal sizes in the product massecuite.

Operationally, it is important to use seed of consistent mean size and narrow size distribution and avoid the supply of seed crystals with mean size which is too small.

If seed crystals are too small, the effect is to produce a very large increase in the spread of the crystal sizes in the early cells, to the significant detriment of the CSD in the product crystals (Broadfoot, 1992).

**Circulation velocity and steam/vapour usage**

The attainment of a strong circulation velocity of massecuite in a continuous pan requires careful selection of the diameter and length of the tubes, the heating surface area/volume ratio and the profiles of the pan shell and calandria.

It is desirable to obtain sufficient velocity through all sections of the massecuite flow path to avoid settling of crystals and importantly, to allow the supersaturation driving force to be set to a high value (without incurring nucleation), and so maximise the sucrose deposition rate.

In practice, the optimum level for the massecuite above the top tube plate which promotes a strong circulation rolling action of massecuite from above the calandria into the downtakes, depends primarily on the brix (viscosity) of the massecuite.

The vacuum in the head space of the pan and the steam rate to the calandria affect the circulation velocity to a lesser extent.

As a guide, the preferred massecuite level above the top tube plate for maximising the circulation velocity has been found for Australian boiling conditions to be:

- C massecuite: 300–400 mm
- B massecuite: 400 mm
- A massecuite: 600 mm
- HG seed massecuite: 900 mm
Recently, SRI undertook velocity measurements across the width of the downtake of an SRI continuous A pan using a hot film anemometer, mounted on a retractable pipe housing (Rackemann and Stephens, 2002; Broadfoot et al., 2004).

The velocity was determined to be reasonably consistent across the full width of the downtake and was typically 0.07 m/s to 0.12 m/s (4 to 7 m/min).
On a volumetric flow basis these values compare favourably with equivalent measurements in the downtakes of batch A massecuite pans. The hot film anemometer technique can be utilised at most positions within the circulation flow path and is very useful in determining regions of slow movement or of ‘settled’ massecuite, and for improving pan design.

An ‘open’ flow path for the massecuite, without restrictions, is desirable. A freely circulating massecuite flow path will allow the steam/vapour usage on the pan to be maintained as close as possible to the theoretical minimum evaporation rate for the duty, and avoid the need for excessive steam/vapour and balancing water, just to ensure that adequate circulation is achieved. A freely circulating massecuite flow will also allow vapour supply of lower pressure to be used. One of the major advantages of continuous pans compared with batch pans is the ability to operate, in general, with less balancing water and hence consume less steam per tonne of massecuite production.

Broadfoot (1999) provides data on the steam consumption of several SRI continuous pans operating in the Australian industry. The typical steam consumptions of the pans for the different massecuite boiling duties are shown in Table 2.

<table>
<thead>
<tr>
<th>Massecuite type</th>
<th>Steam consumption, tonnes steam per tonne massecuite produced</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.28</td>
</tr>
<tr>
<td>B</td>
<td>0.29</td>
</tr>
<tr>
<td>A</td>
<td>0.30</td>
</tr>
<tr>
<td>HG seed</td>
<td>0.31</td>
</tr>
</tbody>
</table>

Most Australian factories currently use exhaust steam from the back pressure turbines for pan boiling. However, as the industry progresses towards more energy efficient operations, e.g. for power export through cogeneration, many of the continuous pans will be changed to operate on bleed vapour from the evaporators. Further installations of continuous pans are expected as many Australian factories seek to reduce their total process steam consumption, and reduce the magnitude of variation of the steam/vapour consumption on the pan stage.

Control and supervision

The benefits of continuous boiling are best realised through the maintenance of consistent operation, without the need for excessively high or low production rates (Pozzetti and Sheedy, 1989). In practice, continuous pans can operate effectively through production rates of 50% to 120% of the design rate but, for consistently good performance with respect to exhaustion and fouling of the heating surfaces, a consistent production condition should be sought. It is particularly important that continuous pans avoid the need to idle production e.g. owing to lack of feed syrup. For this reason, continuous pans should not be oversized for the required boiling duty. Fortunately, horizontal continuous pans can be expanded to suit an increased crushing rate of a factory, if required. This feature is discussed later in the paper.

Continuous pans operate best when required changes to the production rate and boiling conditions are small and infrequent. To achieve this goal, continuous pans require:

(a) Suitable control systems. SRI favours the use of the ‘forced feed’ method for regulating the massecuite conditions (supersaturation and crystal content) in individual cells in order to achieve fast crystallisation rates (high productivities) without fine grain formation (Broadfoot et al., 1991). This method of control, which is shown schematically in Figure 3 is particularly beneficial for high purity boilings (A, B and HG seed massecuite) where fast growth rates are achieved. Typically, the average crystal growth rates in the different duties are:

\[
\begin{align*}
\text{HG seed} & \quad 100-110 \text{ pm/h} \\
\text{A massecuite} & \quad 100-110 \text{ pm/h} \\
\text{B massecuite} & \quad 80 \text{ pm/h} \\
\text{C massecuite} & \quad 20-25 \text{ pm/h}
\end{align*}
\]

For the SRI continuous A pan at Tully Mill (of 150 m³ massecuite volume), the sucrose deposition rate in the pan (for an 89 purity A massecuite) is 36 t/h and the linear crystal growth rate is approximately 110 pm/h. These data indicate the extent to which the pan is operated to a high productivity level. The volumetric efficiency for this pan is 1.30.
Computer control systems are now commonly used to set all the control functions of the continuous pan, including the seed addition rate to the first cell, the selection of the syrup/molasses feed rates to the individual cells, vapour supply rates etc.

(b) Effective procedures to allow supervisory staff to determine the required sustainable production rate for the continuous pan over the next four to eight hours. This may involve simple assessments based on stock tank movements and projected crushing conditions, to more sophisticated computer assessments of individual production rates of pans based on crushing rate data, cane supply information, current cane analysis data etc.

Fig. 3—Schematic of control system employing the ‘forced feed’ method.

Minimisation/elimination of crust formation

Experience over several years has determined that the most effective means to minimise, and in fact eliminate, crust formation on tubes, walls etc. is to:

(i) Maintain consistent production conditions and definitely avoid periods of idling or stopping.

(ii) Operate with the minimum rate of steam/vapour to the calandria(s) for the required production rate. Strongly circulating pans avoid the need to use excess steam and balancing water in order to maintain adequate circulation of the massecuite. The benefit of minimising the steam/vapour rate is that the saturation temperature within the calandria vapour space is reduced, and the tendency for crust to form on the tubes is reduced compared with operation at high steam rates (Watson and Broadfoot, 1998). Operation with reduced steam rates also minimises the amount of splashing of massecuite onto the walls.

In order to extend the production time between boilouts, it is important that high steam rates (leading to high calandria pressures and temperatures) are avoided. In this regard, after a boilout, the temptation to operate at a high production rate in order to reduce accumulated stocks rapidly, must be avoided. The steam rate must be kept at a relatively low value and stock quantities reduced gradually over the next 24 hours.

(iii) Spray feed material intermittently or on a continual basis onto the walls, baffles etc. above the massecuite surface.
Exhaustion of product massecuite

Exhaustion performance is also closely related to the circulation characteristics of the pan, as a strong circulation movement allows for tighter control on the operating supersaturation and production of massecuite at high brix. As is well established for batch boiling of C massecuites (McGrath and Webster, 1984), increased exhaustion performance in continuous C pans is obtained by using lower conductivity setpoints through successive cells.

Figure 4 shows a typical profile of the dry substance of C massecuite through an SRI continuous C pan. The dry substance values were determined using the vacuum oven drying method (Anon., 1991). The B molasses feed would typically be supplied over the first two thirds of the pan and balancing water supplied to the remaining cells to complete the exhaustion. For A and B massecuite boilings, the balancing water supply is restricted normally to the final cell only.

Figure 4 also shows the profile of the dry substance values for a continuous A massecuite boiling. There is a strong similarity in the profiles, although the A massecuite naturally is boiled at lower dry substance values.

Table 3 provides typical analyses for the product massecuites for the four boiling duties. The high grade seed production is typically held at about 40% crystal content and is not exhausted further as is a strike massecuite (A, B and C massecuite). The usual practice in Australian factories is to cool both the A and B product massecuites without prior cooking crystallisation. Hence, a strong emphasis is given to producing well exhausted A and B massecuites. The C massecuites are typically processed through cooling crystallisers with residence times between 10 and 20 hours prior to cooling. In order to maximise crystallisation and sugar recovery, pan discharge C massecuites are boiled to high brix (dry substance greater than 92) and have high viscosity (typically 200 to 250 Pa.s at pan discharge).

![Profile of massecuite dry substance data for SRI continuous A and C pans.](image)

**Fig. 4**—Profile of massecuite dry substance data for SRI continuous A and C pans.

<table>
<thead>
<tr>
<th>Massecuite type</th>
<th>Massecuite purity</th>
<th>Crystal content, % on massecuite</th>
<th>Dry substance</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>66</td>
<td>30–32</td>
<td>92.5</td>
</tr>
<tr>
<td>B</td>
<td>83</td>
<td>47–49</td>
<td>91.5</td>
</tr>
<tr>
<td>A</td>
<td>89</td>
<td>53–55</td>
<td>91.0</td>
</tr>
<tr>
<td>HG seed</td>
<td>90</td>
<td>38–40</td>
<td>89.0</td>
</tr>
</tbody>
</table>

Table 3—Typical analyses of the product massecuites from continuous pans in Australian boiling practice.
The key to achieving good exhaustion performance from continuous pans is to maintain an adequately high crystal content in all cells, and to provide to the first cell, a good quality seed massecuite or magma, which is also of high crystal content.

**Modular design of pans**

SRI has two different designs of continuous pans; one employs sloping top and bottom tube plates with welded in mild steel tubes, and the other has flat top and bottom tube plates and is suitable for expanded in stainless steel tubes.

Both incorporate the modular design (i.e. where groups of cells are arranged on separate calandria modules). Even though the modular arrangement is slightly more expensive to construct, it is preferred as there are many advantages including:

1. Simplified procedures for start-up, shutdown and boilout operations. The modular design reduces the time taken for the boilout operation compared with a continuous pan of single calandria construction. Details of the operational procedures employed at Tully Mill to conduct a boilout for the continuous A pan are given by Broadfoot et al. (2004). Of note, the average time for the boilout (from ceasing to feed liquor to the pan to the restart of massecuite discharge from the pan) is only 5.3 hours.
2. Ability to use vapour from different sources (e.g. vapour 1 and vapour 2) for different modules, if desired.
3. Ability to set the vapour flow rate to suit the group of cells on the separate calandria module and so reduce the total vapour usage and movement water usage of the pan, compared with that for a single calandria construction.
4. More effective transfer of vapour within each calandria owing to the shorter flow path for vapour to flow from the vapour inlet (located at near the mid-position of the module) to the extremities of the calandria space.
5. Easy addition of an extra module if required. This avoids the need to install an oversized pan when a pan is first installed and the crushing rate is substantially less than is planned following an expansion. By way of example, Proserpine Mill added two extra modules (one at the seed entry end and one at the product end) to increase the capacity of their SRI C pan from 100 m³ to 140 m³, to accommodate a major expansion in factory throughput (Watson and Broadfoot, 1998). The disadvantages associated with installing an oversized pan are capital cost, steam wastage, sugar degradation and increased colouration of the massecuite and mother molasses.

**Recent and future developments in continuous pan design**

Two major developments in the design of continuous pans during recent years have been the incorporation of mechanical agitators, e.g. in the final heavy up cells (Journet, 1996; Watson and Broadfoot, 1998) and more effective use of the incondensible gases from the calandria to the base of the pan (Vermeulen and Pillay, 2000).

SRI is currently evaluating a new design of incondensible gas distribution system on batch and continuous pans as a means to significantly boost circulation movement. Initial results look very promising in terms of the increase in circulation movement that can be achieved.

**Conclusions**

There are many aspects to consider for the effective design and operation of continuous vacuum pans. Considerable research has been undertaken over many years by research organisations, equipment manufacturers and sugar factories and the benefits of that research are being implemented into improved designs.

The most important parameter, which is fundamental to the design, is to produce a strong circulation movement while operating on a low steam consumption rate.

**Acknowledgements**

The assistance of colleagues at SRI, Australian sugar factories, and overseas client factories in progressing the development of SRI continuous pans is acknowledged.

**REFERENCES**


LA CONCEPTION ET L'OPÉRATION DES CUITES CONTINUES POUR OPTIMISER LA PERFORMANCE

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MOTS CLEFS: Cuites Continues, Conception, Opération, Circulation, Efficience Volumétrique.

Résumé

LES CUITES continues offrent des avantages certains en terme de la capacité volumétrique, en comparaison avec les cuites discontinues. On obtient d'autres avantages comme une économie de vapeur, moins de main d'œuvre, et une meilleure qualité de massecuite. Pour réaliser ces avantages il faut toutefois conduire les cuites continues à des taux de déposition de saccharose assez forts, et il faut minimiser les périodes non opérationnelles comme celle du nettoyage. Le papier présente des idées sur la conception et l'opération des cuites continues pour maximiser les avantages. On donne aussi des résultats pour illustrer l'importance de ces facteurs. Ces résultats comprennent des vitesses de massecuite, des temps de séjour, l'épuisement, et des paramètres pour juger la qualité des cristaux. On discute aussi des possibilités pour réduire les périodes non opérationnelles, et la conception de nouvelles installations.

DISEÑO Y CRITERIOS DE OPERACIÓN PARA MAXIMIZAR EL BENEFICIO DE LOS TACHOS CONTINUOS AL VACÍO

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PALABRAS CLAVE: Tachos Continuos, Diseño, Operación, Circulación, Eficiencia Volumétrica.

Resumen

LOS TACHOS continuos al vacío proporcionan ventajas significativas para el logro de un uso más efectivo de la capacidad volumétrica que los tachos de bache. Otras ventajas son una supervisión reducida, beneficios para la economía del vapor y consistencia en la composición del producto masacocido. Sin embargo, con el objeto de maximizar los beneficios, los tachos continuos deben ser operados a altas tasas de concentración de sacarosa y ser capaces de minimizar los efectos de cualquier limitación, tales como los tiempos fuera de línea para la limpieza. Esta ponencia trata sobre varios criterios importantes de diseño y operación para maximizar los beneficios de los tachos continuos en la operación general de la fábrica. Se presentan datos de los tachos continuos en la operación, para resaltar la importancia de dichos criterios. Tales datos incluyen mediciones en la velocidad de la circulación de flujo de la masacocida, datos sobre la distribución del tiempo de residencia, descarga de la masacocida y datos sobre la calidad de los cristales. Se toman en cuenta los cambios de diseño para futuras instalaciones de tachos continuos, así como de formas para minimizar los efectos de los tiempos fuera de la operación.