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STRATEGIES TO OPTIMISE CONTINUOUS PAN PERFORMANCE

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Introduction

Continuous vacuum pans (CVPs) should operate for the most part at constant conditions which are readily controlled by instrumentation. Unlike batch pans, they therefore require minimal operator intervention once started. Their status varies little and is usually recorded and adjusted remotely from a control room. For this reason, CVPs are often neglected by the operators, other than for routine probe cleaning and occasional adjustments.

At many factories, process staff tend to regard the CVPs as 'fixed' equipment to be operated at the supplier's recommended settings. So, when circumstances change, the pan station requirements such as throughput rate, juice quality, steam shortage, and sugar quality problems are managed mainly by changes in the batch pan boilings. However, in many pan stations the continuous pans perform most of the crystallization, and these are a flexible resource that should be the first turned to in order to meet changing priorities.

Key requirements such as throughput, recoveries, sugar quality and energy efficiency, vary between factories and often change within a season. This paper reviews CVP operating strategies and equipment that can be used to meet various objectives, some of which may be conflicting (e.g. throughput vs. exhaustion). These are explained with reference to pan boiling theory. The effects of seed quality and quantity, feed conditioning, Brix and shape of Brix curves (convex, linear or concave) and boiling pressure (and hence temperature) are discussed.

Basics of sucrose crystallization in pans

Sugar crystal formation and growth in pans are determined by the solubility characteristics of sucrose. These are typically of the form of the curves in Figure 1. The saturation curve represents the normal maximum amount of sucrose that can be held in solution at the given purity and temperature over the long term. Below this concentration, in the '*undersaturated zone'*, any existing crystals will dissolve. However, significantly more sucrose than the saturation amount may be carried in solution temporarily before crystallizing out either onto existing crystals or by spontaneously forming new crystals. The supersaturated zone in which this condition prevails is known as the *'metastable zone'* and it is within this zone that the sugar crystallization process in pans and crystallisers is conducted. The nearer to the top of the zone (maximum supersaturation), the more rapid the rate of sucrose deposition and crystal growth and the better the exhaustion. Above the maximum supersaturation is the *'labile zone'* in which spontaneous crystallization (formation of false grain) is probable.

The values of these ranges are dependent on temperature, Brix and purity (ratio of sucrose to total dissolved solids).

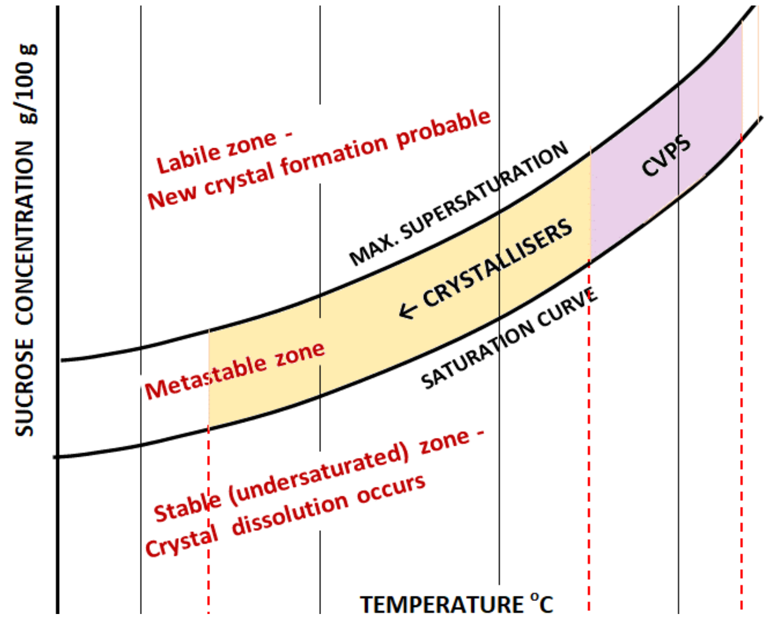

Figure 1. Typical sucrose solubility ranges for CVPs and crystallisers.

Understanding these curves provides guidance on how to use the continuous pans to achieve various process objectives.

Brix

CVPs usually start with seed at, say 89.5 to 91.0% refractometer Brix in the first compartment and, using increasing settings of the successive compartmental Brix controllers, this massecuite is increased through the pan to a final value of, say 93.5% for an A pan or 97.0% for a C pan. The targeted rate of increase may follow one of various "Brix profiles" (see Figure 2).

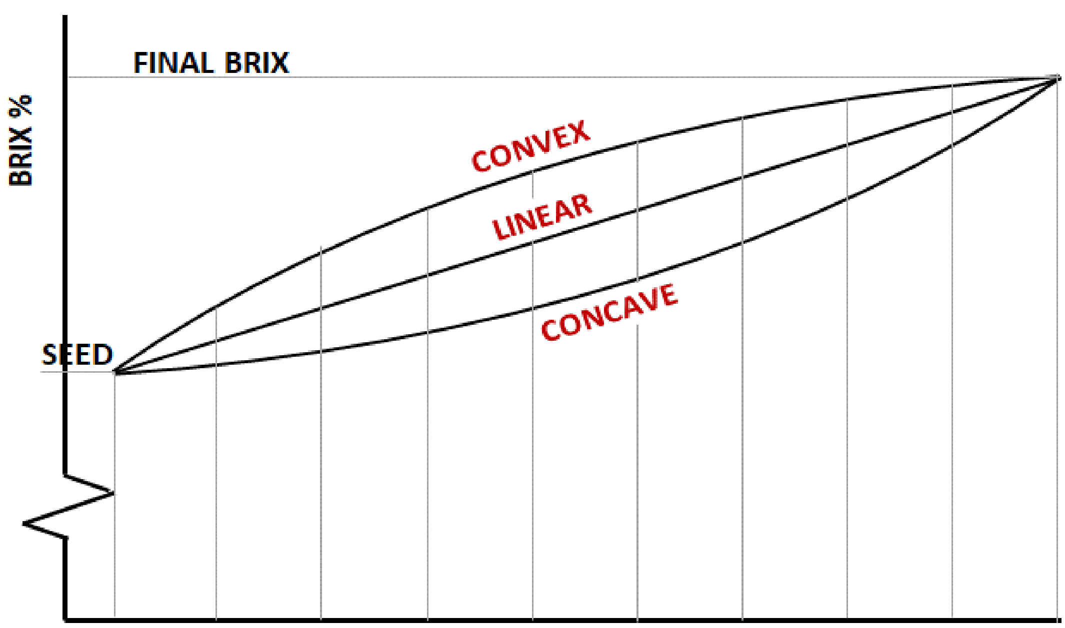

Figure 2. Alternative Brix profiles for 10-compartment CVP.

The most appropriate profile will depend on the relative importance of what may be conflicting objectives. To help decide on a profile:

High Brix – especially in the final compartments – increases exhaustion due to the high dissolved solids content driving sucrose out of solution, but high Brix brings high massecuite viscosity, which impedes circulation and sucrose migration to crystals. High Brix also reduces turbulence, HTC and evaporation rate (production).

Thus, for maximum exhaustion, operate at upper range of the metastable zone (higher Brixes), using a linear or slightly convex Brix profile.

But if throughput (high evaporation rates) is the top priority, operate at lower Brix for much of the pan, Brixing up in the final compartments only ('concave Brix profile').

These considerations may lead to the selection of a compromise profile, with Brix kept low in the range for much of the pan, but raised (not too abruptly) to high Brix for the final compartments (Figure 3). Note that large increases between adjacent compartments may risk false grain formation. With this profile, pan exhaustion will be lower than from a full convex profile (less time in the pan at high Brix), but some of the foregone exhaustion should be recovered in the crystallisers.

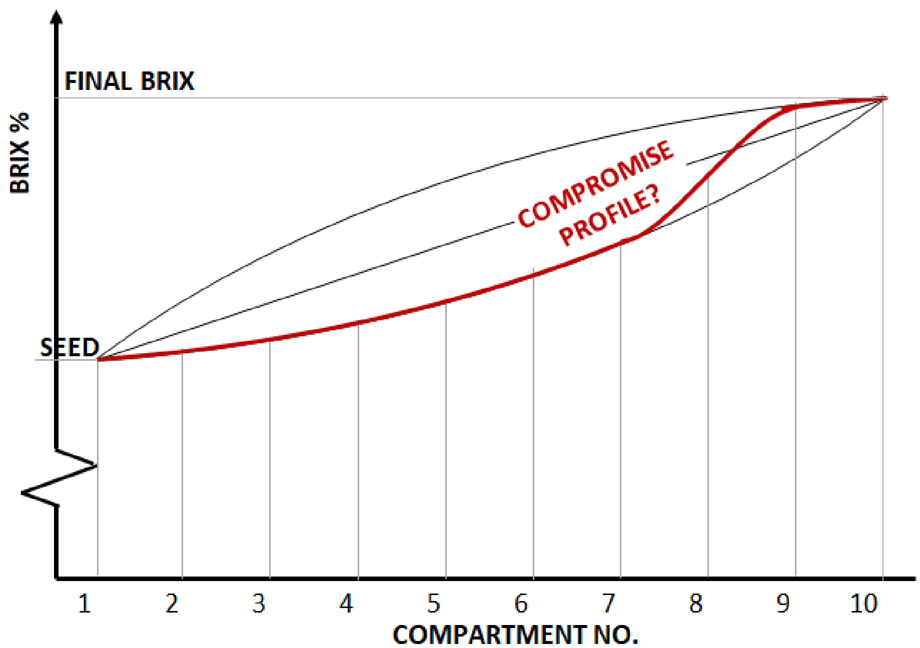

Figure 3. Compromise profile for throughput and exhaustion.

Temperature (pan boiling pressure)

The pan boiling temperature is controlled by the boiling pressure. Low temperatures (low absolute boiling pressures) reduce sucrose solubility and hence promote exhaustion. But viscosity approximately doubles for every 5°C lower temperature, and this impedes circulation and sucrose deposition, impeding exhaustion. Here again, an optimum for the pan concerned must be determined by practical testing of that pan.

An important consideration in deciding the pressure/temperature is the risk of initiating *Maillard* reaction, especially in low purity C CVPs. Thanks to their lower boiling heads, CVPs generally boil at lower temperatures than batch pans, but are not immune to this risk. To minimise the risk, Rein (2017) recommends C pan boiling pressures of 12-13 kPa abs. These may not be achievable by some vacuum systems and many types of CVPs exhibit poor circulation at these temperatures, in which case the lowest practical pressure should be selected.

Seed and feed supplies

The seed – be it from a virgin boiling or magma - must be of good quality with uniform, fines-free crystals (low CV) and the correct size and quantity of crystals. Too few crystals will risk spontaneous nucleation (false grain), whereas too many will result in a too small final crystal size. Once the desired quantity has been established, this can be maintained by setting the seed supply proportional to the actual syrup/molasses feed flow.

For good CVP performance, consistent quality feed (syrup or molasses) is necessary. Ideally, this should be provided from a conditioned feed supply tank, preferably close to the pan. Both temperature and Brix may be conditioned, but temperature conditioning is the more important of these, as the Brix controls will adjust for gradual changes in Brix. It is recommended that the feed temperature be hot (>70°C). If feed is injected below the calandria, this aids good mixing and flash stimulation of circulation. A temperature well above saturation in a well-stirred supply tank will also ensure that any false grain is dissolved before feeding. This is especially important if the feed includes some remelt. Remelt should be regularly checked by microscope for any residual fines.

Massecuite flow

Under steady conditions, all crystals grow at a similar rate, so for a good (low) final CV it is important that the seed flows through the pan in good plug flow. The importance of a good CV has been emphasised *inter alia* by Broadfoot (1992), Journet (1994), Thelwall (2000), Moor (2016) and Rein (2017). The main reason is for better centrifuging (free draining because the apertures between crystals are open, not blocked by smaller crystals). This means that less washing is needed and there are no fines to be dissolved or to pass through the screens. This improves exhaustion, reduces losses and reduces the energy requirement of reboiling. Affination is also easier with uniform crystals, which is why CV is often included in export specifications.

The approach to true plug flow can be measured by tracer testing and applying the ‘equivalent mixed tanks-in-series’ model as described by Wright and Broadfoot (1977). Moor *et al* (2019) quoted eleven published tanks-in-series results for various types of CVP and concluded that the best results are from horizontally configured vertical tube pans that exhibit good flow patterns both transversely (as in Figure 4) and longitudinally (as in Figure 5). These computational fluid dynamics (CFD) simulations are from a report by du Plessis of ESTEQ Engineering (2015). The best plug flow of the quoted results was from the Bosch CVP at NAT&L in Vietnam and the next best from the SRI pan at Mossman, Australia, both of which include transverse partial baffles within compartments that prevent undue forward and back flow in the longitudinal direction.

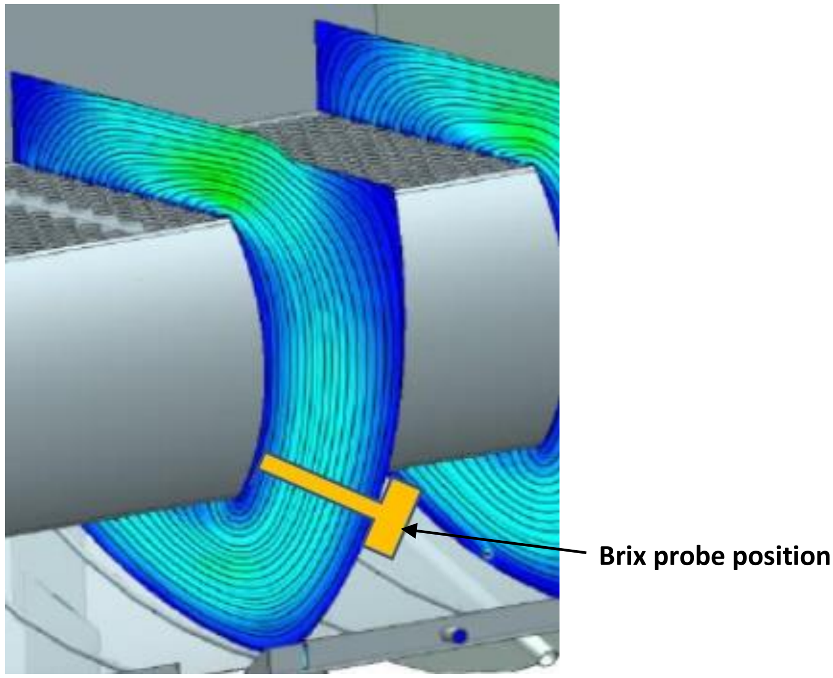

Figure 4. Transverse flow pattern in Bosch CVP.

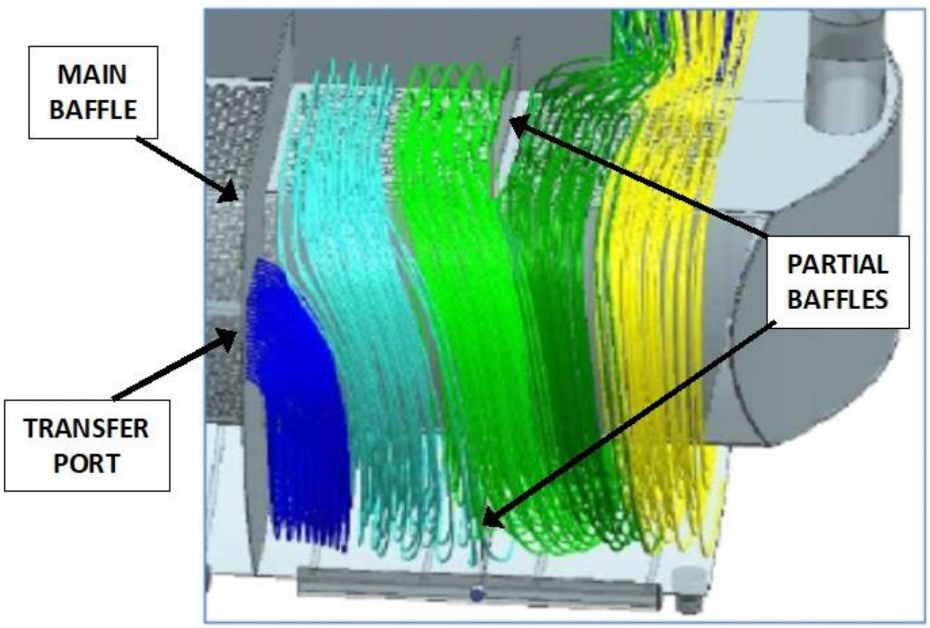

Figure 5. Arrangements that provide longitudinal plug flow in a Bosch CVP.

The plug flow characteristics of a CVP are largely determined by the pan design features such as circulation profile, flow baffles, inter-compartment transfer arrangements, feed position and jigger or other circulation aids. Little can be done to align massecuite flows by operating strategy, other than by ensuring steady operation. However, the flow patterns in many poor pans can be improved at modest cost by simple changes to features that influence the flow and these should be explored.

Circulation and turbulence

Vigorous circulation and turbulence are essential for both good evaporation and good exhaustion. Well-designed CVPs generally have good natural circulation, but even in good pans, circulation is reduced in the final compartments as Brix is increased to maximise exhaustion.

Various techniques are available to enhance circulation in unstirred pans. Most common is the use of jiggers, for which pan heating vapour is usually used. However, if energy economy is a priority, Moor (2002) has shown that incondensables from the calandria will always be of sufficient pressure for use as jiggers.

The jigger application arrangements are important. SRI has developed a jigger feed system in which the jigger steam is injected through multiple laser-drilled perforations that are too small to permit back-flow of massecuite and provide an ideal distribution of fine bubbles (Rackemann and Broadfoot, 2007). As an alternative, Bosch inject their jigger steam through multiple nozzles (usually 12 per compartment) evenly distributed beneath the full area of the calandria.

Bosch also use under-base heating to stimulate circulation (Moor, 2007).

It was widely believed that short tubes promoted good circulation in CVPs, but Moor *et al.* (2018) produced evidence that longer tubes perform as well as or better than shorter tubes. The greater buoyancy from more vapour bubbles per longer tube apparently more than counters the additional friction drag and higher boiling temperature at the bottom of the tube.

Measurement of CVP process performance

A continuous pan is required to produce uniform grain of a specified final size, and to achieve optimal exhaustion of the feed liquor. Measurement of these functions is particularly important in the case of C pans which are a direct profit centre in sugar factories. Some additional data and pan floor equipment is required.

Measurement of grain. Photographs of the seed and massecuite leaving the pan should be available twice per shift, showing the crystals with size measurements in microns at a suitable magnification. These photographs should be retained in a computer folder with hard copies printed for the daily report. The photographs should be dated and have Brix and purity data annotated as well as the pan boiler’s name.

In addition to providing an immediate check on the pan’s performance, changes in crystal shape due to the influence of impurities can be monitored over a period.

A microscope, camera, and measuring software should be available.

Measurement of exhaustion. A pan Nutsch should be carried out once per shift on hot massecuite leaving the pan. This will enable the pan exhaustion to be calculated. The pan exhaustion will provide a performance parameter which allows comparisons with other pans and is independent of any subsequent work done by crystallisers or losses suffered across centrifuging. The Nutsch apparatus needs to be located on the pan floor for this to be effective, with only the extracted mother liquor sent to the laboratory for analysis.

Instrumentation

The operating strategy for a CVP is entirely dependent on accurate information from and control of the pan. It is essential to use high quality, reliable sensors to ensure good performance. In particular, control of the dissolved solids concentration (or Brix) is key. There are no commercial instruments that can measure this directly, but various instruments are available that provide reliable inferred measurements of the required values (Rein, 2017).

For C and B continuous pans, *conductivity probes*, which measure the electrical conductivity of the mother liquor, provide suitable, cost-effective control transducers. However, pure sucrose solutions do not conduct electricity and conductivity probes are not reliable for higher purity massecuites.

For the higher purity A pans, the most cost-effective transducers are good quality *RF probes* (Radford and Cox, 1986). These measure the radio frequency properties of the massecuite and can be tuned to respond predominantly either to the mother liquor conductivity which is related to dissolved solids, or to capacitance, which is related to the crystal content. They can therefore be used for both low and high purity massecuites and are the widely preferred transducers for A CVPs.

Conductivity and RF probes (at a lower rate) are liable to incrustation over time in continuous pans, which leads to signal drift and they need to be removed periodically for a quick mechanical clean. Designs of both conductivity and RF probes are now available that incorporate probe heating (Reichard *et al*, 1992) and/or on-line washing, both of which reduce the frequency of mechanical cleaning.
Microwave absorption units are higher-cost transducers that are suitable for both low and high purity massecuites. These respond directly to water content so accurately measure total solids. An advantage is that they are not affected by purity changes (Saska and Rein, 2001).

Viscosity transducers are used in some batch pans, but generally not in CVPs.

Nuclear density meters have also been used in batch pans but are high cost and generally eschewed due to environmental reasons.

Whatever transducers are used, they need to be calibrated initially against actual laboratory Brix measurements. Thereafter, their readings will invariably “drift” in service due to scaling, changes in the massecuite composition and possibly in the electronics. It is therefore essential that samples be drawn regularly from each CVP compartment and measured in the laboratory. These laboratory results should be charted against the transducer readings. This chart should be maintained at the pan station so that the pan boiler is immediately aware of drift or sudden deviations and can take appropriate corrective action (probe cleaning or perhaps even recalibration).

It is important that the Brix transducers be positioned where they are exposed to representative bubble-free sample of the massecuite. The ideal position in most horizontally configured vertical tube CVPs will normally be in the downcomer as shown in Figure 4. In large pans with wide downcomers, care must be taken that the probe projects beyond any quiescent zone close to the shell.

On-line steam-outs

CVPs do not suffer the frequent energy losses of batch pans during the boil-outs between each strike, but do need occasional boil-outs to remove deposits that have built up in the tubes and internal surfaces. These are more frequent in high purity boilings where incrustation is more rapid.

A simple technique that significantly extends the periods between energy-wasting boil-outs is *on-line steam outs.* The usual procedure is:

- Shut off injection water to the condenser (vacuum reduces);
- Leave calandria steam valve, incondensable gas valves, vacuum pump, and RF/conductivity probe settings unchanged. Optional: Open all jigger steam valves fully;
- Open steam/vapour into the body of the pan via a large steam-out valve provided for this purpose above the massecuite;
- Vacuum falls away and within a few minutes (usually about 3-5 minutes) the massecuite temperature will reach 90-95°C. At this temperature, deposits in the tubes and on internal baffles and shell soften and run off;
- Once this massecuite temperature has been reached, close the pan steaming and gradually re-open injection water. The pan will boil vigorously as it flashes back down to normal operating pressure. The vigorous boiling helps to dislodge the softened deposits in the tubes.
- Continue normal boiling.

The time at elevated temperature is too short for crystal dissolution or colour formation. The process is easily automated. The ideal frequency of the steam-outs should be decided by experience for the CVP concerned, but is often once per shift or once per day for A pans and less frequently for B or C pans.

Conclusions

Although the principle of continuous pan boiling is simple and modern CVPs are automated to operate with minimal operator intervention, they must not be neglected by the pan boilers. Understanding the underlying crystallisation process can enable the process staff to steer an optimum path between the often-conflicting objectives of high evaporation rates, high exhaustions, good quality sugar, energy efficiency and plant availability.

Some optimisation – particularly of sugar quality and massecuite circulation - may not be possible by operational changes alone and may require physical modifications to the pan.

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