SYMPOSIA PRESENTATIONS

REQUIREMENTS FOR SUCCESSFUL IMPLEMENTATION OF CONTINUOUS PROCESSES

Criteria for successful continuous plant design

The general conditions favoring either batch or continuous systems are well summarized by Levenspiel in relation to chemical reactors:

"The batch reactor has the advantage of small instrumentation cost and flexibility of operation (may be shut down easily and quickly). It has the disadvantage of higher labor and handling cost, often considerable shut down time to empty, clean out, and refill, and poorer quality control of the product. Hence we may generalize to state that the batch reactor is well suited to produce small amounts of material or to produce many different products from one piece of equipment. On the other hand for the chemical treatment of materials in large amounts, the continuous process is nearly always found to be more economical."

This analysis is true for batch and continuous pans as well. As factories have generally become larger and have been looking to improve operating efficiencies, the continuous pan has generally proved to be more cost-effective.

One of the most important factors in the successful design of a continuous system is achieving the correct flow characteristics. For example, the conversion from batch to continuous clarification in sugar mills was highly unsuccessful measured in terms of the volume of the continuous systems vs. the batch systems. Early designs of clarifier of the Rapidorr type were highly inefficient, requiring very large residence times. Subsequent modifications of these devices to give proper attention to flow characteristics have reduced the retention time by a factor of about 4. Proper consideration was given to obtaining plug flow characteristics in the design of the SRI type of clarifier, which operates at residence times lower than those in the most efficient modified Rapidorr clarifiers by a factor 2 to 3.

Taking the analogy with chemical reactors one stage further, the two major types of continuous reactors are plug flow and back-mix reactors. In the former, the composition of the material changes along the length of the reactor, whereas in the back-mix reactor all the contents of the vessel are of the same composition.

In general, the plug flow system is capable of a greater conversion, unless a zero order reaction is being considered, but the back-mix system is generally easier to control (Shinskey).

In the case of a continuous vacuum pan it is desirable to have a plug flow system. This ensures that all crystals have the same residence time, thus ensuring a uniform crystal size distribution in the product massecuite. It also promotes the overall rate of crystallization, since mother liquor purity changes along the length...
of the system and crystallization from higher purity mother liquor occurs at a faster rate in the first part of the system. In a back-mix system the composition in the entire system is the same as the composition of massecuite product and the crystallization rate is low because of the low purity mother liquor. The first requirement then for a continuous vacuum pan is to have a close approach to plug flow to optimize crystallization and make best use of installed volume.

Although plug flow systems are generally more efficient, they are more difficult to control than back-mix systems. Adequate means of control is essential if plug flow systems are to be successful. This requires that suitable measurement transducers are available and that control is effective under all conditions, particularly as throughput rate changes.

The problem of achieving a close approach to plug flow requires empirical experimentation, since scale up from small systems is generally not successful. Product size distribution usually tends to widen with increasing scale of operation (Waldie17). In the same way homogeneous crystallization conditions are easy to achieve on a small scale, but careful attention needs to be given to the full scale plant system to ensure that uniform crystallization conditions are achieved. This requires the absence of any stagnant areas or dead zones and uniform conditions of temperature and composition.

A final requirement of a continuous system should be that it is reliable and simple to operate.

Factors inhibiting the change from batch to continuous pan boiling

It is instructive to look at the reasons for why it has taken so long for pan boiling to be successful on a continuous rather than a batch basis. These are as follows:

(a) Low settling rates of sugar crystals

Continuous crystallizers have been available for many years for crystallizing other materials from solutions such as salt or alum. These crystallizers are classed as “mixed suspension classified product removal” crystallizers. Solid product of the right crystal size can be separated out by settling at the outlet from the crystallizer system. Undersized crystals and mother liquor can then be recycled. However this approach is not feasible with sugar since the high viscosity of the mother liquor means that the settling rates of sugar crystals are impossibly slow. Typically the settling rate of a sugar crystal is 0.001 m/sec, whereas settling rates for potassium chloride and alum crystals are 0.04 m/sec and 0.025 m/sec respectively. This implies that continuous sugar crystallizers must be of a “mixed suspension mixed product removal” type and the option of recycling undersized crystal is infeasible, and a number of crystallizer designs developed for other applications are not appropriate.
(b) Residence time distribution of crystals

Because it is not possible to recycle undersized crystals it is important that each crystal remains in the continuous system for roughly the same amount of time so that a uniform size distribution of product crystals can be obtained. An ideal plug flow system would have this characteristic of equal residence times for all crystals. The continuous pan system has to have a close enough approach to plug flow for a reasonable product size distribution to be achieved.

(c) Controllability

Close control of a true plug flow system is difficult to achieve under practical conditions. If a plug flow system operates smoothly with no process upsets then no control is necessary. In practice, however, process disturbances will always be a fact of life and the control system needs to be able to respond. A major process disturbance is change in throughput rate, which has the effect of altering the distance-velocity time lag; making control inherently difficult. This leads to a "variable time constant", or a gain which changes with flow rate (Shinskey). A practical solution to this problem is to arrange the system as a number of cells in series. This makes it possible to control the composition within each cell and providing there are enough cells in series, the flow system gives a close enough approach to plug flow to satisfy the criterion of equal crystal residence times. This aspect is explored in more detail later in the paper.

On-line particle size measurement has not been achieved on an industrial scale, and control of crystallization then has to involve control of supersaturation (Waldie). Continuous pan systems were generally first successfully applied to low grade boilings, where conductivity is a satisfactory method of controlling massicite condition. Application to higher grade massicites has been delayed until the development of suitable cost-effective sensors has been achieved. Suitable control systems for all grades of massicites now exist.

(d) Encrustation

Particularly in high grade boilings, encrustation of surfaces within the continuous pan system can be a severe problem. However, there are a number of ways of overcoming the problem. Developments in the design and operation of continuous pans can minimize encrustation or keep it under control (Rein). It is not proposed to compare the designs of different types of continuous pans. A comprehensive literature survey on the development of continuous vacuum pans
has been published by Rouillard\textsuperscript{15}. Continuous pan designs which have found wide acceptance generally fall within three categories:

(a) **Horizontal multiple compartment pans**

The first pans of this type were installed by Fives-Cail Babcock (FCB). A number of mixed cells in series can give close enough approximation to plug flow to give a reasonable crystal size distribution. A flow system equivalent to about 12 or more tanks in series is generally adequate (Rein et al.\textsuperscript{14}). The Australian SRI pan and the South African Tongaat-Hulett pan fall into the same category, but the heating of massecuite and the circulation patterns in the different. These pans rely on natural circulation.

(b) **True plug flow type pans**

The Langreney pan was designed as a system with a long flow path which attempted to approach true plug flow (Langreney\textsuperscript{8}). The pan essentially consists of a long narrow vessel divided longitudinally into two sections, one of which contains a tubular heating element. A similar approach has been used in the design of a pan for Racecourse factory in Australia (McDougall and Wallace\textsuperscript{9}).

(c) **Multiple batch pan type**

Although attempts have been made to divide conventional batch pans into a number of compartments using radial division plates, these have generally not been successful. However, connection of a number of batch pans in series to form a continuous system has been shown to be effective. Such a system has been in operation at Lage Beet Sugar Factory for a number of years (Austmeyer\textsuperscript{1}). A modification of this system is evident in the BMA vertical crystallization tower used in the beet sugar industry, which consists of four stirred cylindrical vessels placed one on top of the other. Massecuite flow is by gravity from one vessel down to the next (Austmeyer\textsuperscript{1}). However, having only four compartments in series tends to widen the residence time and crystal size distributions.

A number of these designs are finding wide application in sugar factories throughout the world. Ease of operation has been a feature, which first led to acceptance of continuous pans on low grade duty, and has subsequently been extended to high grade boilings with the development of suitable measuring transducers. A feature of the continuous systems has been the lower $\Delta t$ between calandria steam temperature and massecuite temperature. In the cane sugar industry batch pans, this has generally been of the order of 45°C but is closer to 30°C in most continuous pan systems. An advantage of the forced circulation pan design of BMA is the fact that temperature differences can be reduced even further to around 15°C, which can bring additional advantages in terms of steam efficiency.
Systems for continuous production of seed have not yet been successfully demonstrated on a full scale. It is expected that in the foreseeable future, seed will still be produced on a batch basis or else a magma of lower grade crystal will continue to be used as a seed for continuous pans.

Where seed is produced in the beet sugar industry at a size of around 0.1 mm by a batch cooling process, the need has been identified for a continuous system to grow this seed up to a larger size for feeding into existing designs of continuous pans. When starting with a small seed, a lower heating surface/volume ratio is required, since the crystal surface area is low and evaporation is generally faster than crystallization, and natural circulation needs to be augmented with forced circulation. This has led to the development of the Seaford pan (Randall1), which has a lower heating surface/volume ratio and utilizes two horizontal stirrers to assist natural circulation, which fulfills this particular duty.

A COMPARISON OF BATCH AND CONTINUOUS PAN SYSTEMS

A comparison of the features of continuous and batch pan illustrates clearly the advantages and the problems of continuous pan boiling.

Steam economy

The steam demand of continuous pans is steady and not subject to the considerable changes experienced with batch pan boiling. This leads to steadier boiler and evaporator operation, which in itself has been reported to result in improved steam economy. Moreover the low boiling head and the attention given to good circulation in most continuous pans enables a lower grade of vapor to be used in the calandria. For instance vapor II is used in the calandrias of A, B and C continuous pans at Felixton Mill, resulting in significant improvements in fuel economy. In addition, steamings from batch pans are eliminated, again reducing the overall evaporation load.

Where exceptionally high steam economy is sought, the BMA vertical tower continuous pan operates with a very low Δt because of the stirrers and can be used to advantage in association with a mechanical vapor recompressor. Because of the continuous operation vapor can be drawn off the pan and recompressed continuously to provide the calandria steam.

Sugar quality

A consequence of the low boiling head in continuous systems is more uniform crystallization conditions. The boiling hydrostatic head is reduced, and with good circulation, conditions are more favorable for optimizing crystallization.
Comparative tests of batch and continuous pan boiling at Maidstone showed that the color of sugar produced in a continuous pan was on average 16% lower than that produced from batch pans (Rein). Batch pan systems have an advantage in terms of grain size distribution since each crystal in the system has exactly the same residence time. However, extensive measurements of flow characteristics in continuous pan systems have shown that there should be no disadvantage in continuous pans providing adequate attention is given to obtaining a residence time distribution adequately close to plug flow and seed quality is reasonable. Estimates of the improvement in CV (coefficient of variation), obtained in a continuous pan as a function of the number of compartments in the pan and initial starting CV show that the same improvement in CV in a continuous system as is achieved in a batch system is realistically attainable (Rein).

Pan volumes

Generally more efficient use is made of installed pan volume in a continuous system. The ratio massecuite strike volume in a batch pan to massecuite volume in a continuous pan is estimated to be of the order of 1.4 depending on particular circumstances. In addition, since production is continuous, the downtime associated with striking and steaming out pans is saved.

The reduced volume of massecuite being boiled also means that the average boiling times are reduced, leading to associated reductions in sugar degradation and color formation.

Process control

Control of batch pan boilings is generally more complicated than that of continuous pans, although the later tend to have more control loops per pan. Batch pan controls require that set points be changed as the level in the pan increase, but this can easily be incorporated in modern types of programmable controller. Complete automation of a batch pan, however, also requires that a number of on/off valves be automated.

Controls required for a continuous pan are shown in Figure 1. In a multi-compartment pan, generally one loop per compartment is required, but these controls are simple and on/off controllers are often used on this duty. The control loops are easy to maintain and install.
FIGURE 1. Typical control loops on a multi-compartment continuous pan (only 6 compartments are shown).
SYMPOSIA PRESENTATIONS

The calandria pressure can be controlled at a steady value, or it can be regulated to maintain a pre-set evaporation rate, obtained by measuring the condensate flow rate. This "evaporation rate control" is useful in setting throughput rate, or splitting duties equally between two continuous pans boiling the same massecuite.

A different approach has been used on high grade FCB continuous pans. This involves controlling the vapor flow to the pan and regulating the flow to individual compartments in proportion to the steam flow. A nuclear density meter on the massecuite outlet line controls the feed to the last compartment (Chielens and Lavogiez3).

Simple conductivity measurements are adequate for controlling massecuite condition in compartments of B and C pans. However, these are generally not adequate in A-massecuites or refined boilings. Although conductivity is sensitive enough for A-boilings, conductivity probes are susceptible to encrustation which occurs very rapidly, after just a few hours in high grade boilings. It was for this reason in particular that a new type of measurement using radio frequency (RF) to measure massecuite electrical properties was developed. This device has been found to be adequate for both A-massecuite and white refined boilings (Radford et al.10). These RF probes have been used over a number of years in A-massecuite continuous boilings at Maidstone and Felixton Mills.

While batch boilings are still carried out manually in a number of cane growing areas of the world, it is generally advisable to install automatic control if the full benefits are to be achieved on high grade boilings (A-massecuites and white refined boilings). Automatic control of continuous pans on high grade duty is considered to be essential.

Boiling point elevation is more suited to continuous pans than batch pans, since the hydrostatic head is constant. However the temperature probes are also sensitive to encrustation (Love and Chilvers7).

Nuclear density meters have been found to be effective for controlling high grade boilings (Donovan4), and have been widely used, particularly in European sugar factories. However, these instruments are generally far too expensive to install one on each compartment in a continuous pan system, and the RF probes provide a cost-effective alternative.

Even RF probes are not free of encrustation and on A-massecuites are generally removed once a day or once every two days to remove encrustation. This is quickly and easily done on the run and does not disrupt production.
Encrustation on internal pan surfaces

This is a problem which is not encountered in batch boilings since the pans are steamed out after every strike. Neither is this a problem in continuous B or C masscuite boilings which can operate for a whole season without having to be emptied. However, on high grade boilings encrustation of the internal surfaces of the pan can become severe, leading to the formation of lumps.

Experience with encrustation in South African continuous pans and measures which are taken to overcome or cope with encrustation have been reported elsewhere (Rein\textsuperscript{12}). A one week operational period for an A pan is reported in Australia (Broadfoot \textit{et al.}). In South Africa, A-masscuite pans are generally emptied and cleaned out every two weeks. This fits conveniently with a weekly maintenance shutdown, although periods of up to four weeks are possible on this duty. The disruption to production which this represents can be minimized if attention is given to detail. At Felixton the total downtime associated with emptying out continuous A-pans was reduced from 6/4 to 3 1/2 hours (Montocchio\textsuperscript{9}).

The BMA continuous pan system can be installed with the facility to by-pass any one of the four pan stages, so that one stage may be cleaned out at a time with minimum disturbance to production.

Capital cost of installations

Continuous pan systems are generally cheaper to install and maintain. A recent comparative capital cost estimate for a new mill, including only items which are different for the two cases, is shown in Table 1. In this particular case the system employing continuous pans is just over 2/3 rd of the cost of the conventional system with batch pans. One of the reasons for the saving is that a smaller pan house can be built, saving one complete bay.

Operational factors

Re-training of pan boilers who are used to batch pans is required when continuous pan systems are installed. They need to get out of the batch mentality which says that they should boil as fast as possible as the molasses or syrup tank levels build up and look to operating the systems as steadily as possible with minimum changes in throughput rates.

Changes to buffer tank capacity to reduce process inventories are possible with continuous systems. This can only be achieved in practice, however, if good supervision of the production rates of all grades of continuous pans is maintained.
In batch pans entrainment has generally been found to be associated with the operations of filling and cutting over. Because these operations are eliminated in continuous pan boiling, reduced pan entrainment is expected. In addition the condenser load is steady and with continuous operation the quality of the condensate from the calandria is much improved and can be returned with more confidence to the boilers. Smaller vacuum pumps are also possible because of the steadier load.

Experience has shown that continuous pans generally require less supervision than batch pans, particularly on low-grade massecuites. With variable throughput rates, control of the ratio of seed to massecuite has sometimes bothered operators, particularly in attempts to achieve constant massecuite purities and regular crystal sizes. The automation of the seed pump speed in a fixed ratio to molasses or syrup feed to the pan as shown in Figure 1 generally overcomes this problem.

The shutting down of a pan floor with continuous pans is simple. For a 16-hour Monday shutdown, no particular measures are needed with continuous pans, other than perhaps to drop the massecuite level somewhat. The pans are left full and generally no problems are experienced in starting up the pans after the maintenance shutdown.
Pan house flexibility

Batch systems generally do have more flexibility. Depending on the time of season and cane purities, relative qualities of A-B and C- massecuite change. With batch pans the duties of pans can be interchanged to accommodate these variations.

In continuous systems this flexibility disappears and the pans generally need to be sized to cope with peak throughputs. Even so there is a reduction in installed massecuite volume on continuous systems.

Marginal expansion of 10% is also more easily achieved if batch pans are used. A small expansion of this type could be accommodated by installing one additional batch pan and shuffling duties on the pan floor. This is not so easily achieved on continuous pans. However, with horizontal multi-compartment pans it is generally possible to add one or more compartments to gain increased capacity if a small expansion is contemplated.

In general however an expansion of 20% or more is most cost-effectively obtained by the introduction of continuous pans. A number of factories in South Africa have had pan floor expansions undertaken by installing, in the first instance, a continuous C-pan and allocating batch C-pan to A- and/or B- duty. Further expansion involves the incorporation of a B-continuous pan and possibly also a continuous A-pan. This approach ultimately ends up with a more compact pan floor with fewer vacuum pan units, without requiring the extension of the building, which is an inevitable consequence of expansion with additional batch pans.

CONCLUSIONS

Techniques of continuous pan boiling have now been developed to a stage where a widespread swing to the installation of continuous vacuum pans instead of batch systems is underway. Many advantages are being realized which ultimately lead to reduced overall costs of production.

The successful development of a system for continuously producing seed for continuous vacuum pans is still awaited before the pan boiling stage can be made fully continuous.

REFERENCES


On décrit les facteurs qui ont contribué à la transition vers les cuites continues. On compare les cuites discontinues aux cuite continues et on souligne les avantages du système continu. On donne aussi la position actuelle du système continu dans l'industrie de la canne à sucre.

**RESUME**

On décrit les facteurs qui ont contribué à la transition vers les cuites continues. On compare les cuites discontinues aux cuite continues et on souligne les avantages du système continu. On donne aussi la position actuelle du système continu dans l'industrie de la canne à sucre.

**RECIENTES DESARROLLOS EN TACHOS CONTINUOS**

Los factores importantes que han influenciado la transición de los tachos de descarga a los tachos de operación continua, son identificados. En una comparación entre los tachos de descarga y los tachos de operación continua, se demuestra claramente la gran ventaja del sistema de estos últimos; lo cual indica la favorable posición de este sistema de tachos de operación continua en la industria azucarera.