REFEREED PAPER

AUTOMATION OF WHITE PANS AT THE TONGAAT HULETT REFINERY

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Abstract

Pan boiling relies substantially on “art” rather than “science”, thus requiring skilled and experienced operators to optimise crystal sugar production. This puts heavy demands on staffing, training and skills transfer. Particularly in this context, automated pan boiling has the potential to provide substantial benefits in terms of plant capacity, process performance and product quality.

Successful pan automation relies largely on the following aspects: instrumentation that reliably measures appropriate process parameters, a suitable control strategy that relies both on crystallisation fundamentals (science) and practical considerations (art), and control hardware that implements the strategy in a manner that is easy to understand, operate, configure, modify and maintain.

Building on past experience with pan automation, an updated control system was installed on a fourth boiling batch pan at the Tongaat Hulett refinery. Existing measurements were supplemented with a pan stirrer power measurement, an online refractometer and an online microscope. New control hardware, a Yokogawa Distributed Control System (DCS), was installed. Pan boiling control strategies, using the expanded range of measurements available, have been developed. The control strategies have been implemented on the DCS, tested and then operated in production mode for an extended period. The new control strategy has changed the previous manual shock seeding to automated seeding with ball milled slurry in an attempt to approach the ideal of “full seeding”. Work is continuing to replicate the success of this automation to the other four refined sugar batch pans.

This paper describes details of the instrumentation installed, the control strategies implemented and the preliminary results that have been obtained.

Key words: pan boiling, crystallisation, automation, graining, pan control, instrumentation

Introduction

The Tongaat Hulett refinery produces around 450 000 to 560 000 tonnes of refined sugar per annum, which translates to an average melt rate of approximately 68 to 75 tonnes per hour. To accommodate this throughput the white pan house is fitted with five batch pans. Two pans are dedicated to the first boiling whilst the remaining three pans are dedicated to
second, third and fourth boilings. The run off from the fourth boiling (Jet 4) is sent to a separate recovery house for further boiling to exhaust the stream and recycle the recovered sugar. The different refined sugar boilings need to be carefully scheduled to avoid an imbalance of the different sugar streams as the colour of the final product sugar is determined by the mixture of sugar from the different boilings, each of a different colour. The refinery makes two grades of sugar, viz. sugar that meets the EEC 2 specification (export quality) and domestic consumption sugar.

Pan boiling is critical in ensuring that the quality is met in terms of mean aperture (MA) and coefficient of variation (CV) of the product sugar. Massecuite containing crystals with a poor MA and CV does not cure (centrifuge) well and consequently can result in high colour sugar. Small and irregular grains in this sugar also make it difficult to dry. In this situation the sugar is rejected and reprocessing costs are incurred. This critical work of pan boiling is generally manual and therefore relies on the skill and experience of the pan boilers. The reliance on skilled operators renders this area of production vulnerable to high staff turnover and there is a need to rely on inexperienced staff at times. Even if good pan boilers are available, the operation is still manual and is open to inconsistency. Given this background, the Tongaat Hulett refinery decided to take another step in the automation of the refined sugar pans.

The current work on automating the refined sugar pans began with work on a fourth boiling pan (Pan 5). This is a tubular calandria pan fitted with a stirrer (Cox and Purdham, 1989). This automation of conventional boilings had a convenient overlap with work to develop a crystallisation scheme that relies to a large degree on cooling crystallisation (Jensen and Love, 2015) and used Pan 5 to produce seed massecuite for the process. An added advantage of developing an automation scheme on this pan was that the pan has excess capacity for its fourth boiling duty, allowing work on developing and optimising the automation to proceed with a minimised risk of disrupting production.

This paper provides some background to the selection of instrumentation for the pan and a detailed description of the control strategy that has been implemented. A qualitative assessment of the results that have been achieved is given.

**Background to the Automation of Batch Pans**

An excellent summary of the basics of pan boiling is given in the review paper by Wright (1983). Going right back to basics, vacuum pan boiling is evaporative crystallisation conducted under reduced pressure (vacuum) to reduce the boiling temperature. For stable operation the vacuum conditions need to be held constant over the boiling cycle. The pressure at which the boiling takes place (which defines the boiling temperature) is normally a compromise between higher temperatures at which crystallisation rates are faster, and lower temperatures at which product degradation and colour formation are reduced. Although there are pan control strategies where the operating pressure is adjusted to help control the crystallisation process, generally the pressure is held constant throughout the boiling cycle.

In his classical study of the optimum control of batch pan crystallisation, Frew (1973) shows that there are two independent variables of the boiling process that should ideally be controlled by two separate control actions. It is usually most convenient to view these two independent variables as:

- the supersaturation of the mother liquor (the driving force for crystallisation); and
- the crystal content of the massecuite.

The two independent control actions are conveniently viewed as:

- liquor feed rate; and
- pan evaporation rate.
The complexity of pan operation, the reliance on the “art” of pan boiling practised by skilled operators, and the difficulty in automating pan boiling are to a large degree a consequence of a combination of the following factors:

- There are no instruments that can directly measure supersaturation or crystal content online. At best these variables can only be inferred from another measurement or a combination of measurements;
- The more reliable and more appropriate measurements (e.g. refractive index) are generally orders of magnitude more expensive than simple measurements such as temperature, often making it difficult to justify their purchase and use;
- A relatively complex control strategy is normally required when dealing with a “two input (supersaturation of mother liquor and crystal content of massecuite), two output (liquor feed rate and pan evaporation rate)” control system, as encountered with pan boiling. This is in contrast to conventional “single input, single output” control, most frequently implemented using a standard Proportional Integral Derivative (PID) controller. (Shinskey, 1979);
- There are practical limits to the control actions defined by the design of the equipment and process conditions that change through the boiling cycle (e.g. maximum evaporation rate); and
- The physics and chemistry of the boiling/crystallisation process interlink various operating conditions, e.g. when the crystal content is high, the maximum evaporation rate is normally reduced whilst the rate of crystal deposition is high making it impossible to achieve high levels of supersaturation within the mother liquor.

Given the complexity of the batch crystallisation process and the issues around instrumentation (e.g. suitability, cost, reliability), it is not surprising that there continues to be differences of opinion as to the best strategy for batch pan control (Rozsa, 2011). This is particularly so if the choice is made to use only one instrument to monitor the crystallisation process. The argument is: should the single instrument be used to monitor the supersaturation of the mother liquor, try to monitor the crystal content of the massecuite or alternatively select a measurement that is substantially affected by both mother liquor concentration and crystal content.

An online refractometer gives the most appropriate signal for supersaturation (Rozsa, 2011) as it directly measures the concentration of the mother liquor. A microwave probe gives the most appropriate signal for crystal content (Rozsa, 2011) as it is influenced by crystal content and mother liquor concentration. Normally, the mother liquor concentration will only vary within a small band and will thus only have a small influence on the output. If the mother liquor concentration is measured using an online refractometer, its effect can be compensated for to give a more accurate measure of crystal content.

In raw sugar factories, conventional electrical conductivity is known to provide an appropriate measurement that is affected by both crystal content and mother liquor supersaturation (Wright 1984). As a result it is often the single measurement of choice for controlling pans in raw sugar factories (Schneider, 2003). Conventional electrical conductivity depends on the presence of substantial levels of inorganic, ionic, impurities and as such is not suitable for use on refined sugar boilings.

Ultimately, the decision on how to best automate a batch pan is one that depends on economics and the extent to which more expensive instrumentation and control can be expected to deliver improved performance that will provide the necessary return on investment.
Instruments for Pan Control

There is a range of instrumentation that has been used over the years for either monitoring or controlling the crystallisation process, and a useful review is provided by Taylor and Getaz (2010). The more commonly used instruments are described below. A few pertinent references are provided for a wider discussion of these measurements.

**Nuclear density probes (Rein, 2006)**

These probes use the variation in the absorption of rays from a radioactive source to estimate the density of the surrounding liquid. Since density is closely related to massecuite brix, which is closely correlated with crystal content, the signal they provide is a signal that is mostly sensitive to crystal content. When it is known that there are no crystals present, e.g. at the graining point, the signal will provide an estimate of the level of supersaturation but cannot estimate supersaturation on the mother liquor in the presence of crystal. The use of these probes is diminishing due to concern about the safety of handling radioactive material and the strict regulations regarding owning, handling and disposal of radioactive sources.


A microwave probe measures the effect of the surrounding material on the transmission of extremely short wave radio signals. The primary factor affecting the transmission of the signal is the dielectric constant of the material. Since the dielectric constant of water is substantially different from that of sucrose and other organic compounds, a microwave probe can provide an output with a very good correlation with water content.

As such, a microwave probe is very similar, in terms of process monitoring, to a nuclear density probe, giving a massecuite brix signal that provides a reasonable estimate of crystal content. Similarly, a microwave probe can be used for indicating a graining point but cannot estimate mother liquor supersaturation in the presence of crystal i.e. through the majority of the boiling cycle. These probes generally require calibration, once installed, against samples that need to be analysed by laboratory techniques and if not calibrated accurately the output may be of relative rather than absolute significance (Schneider and Vigh, 2004).

**Stirrer Power (Donovan, 1988)**

The power consumed by a pan stirrer (operating at constant speed) will be predominantly a function of massecuite viscosity and density. In practice it appears that there is very little variation in stirrer power until a steep increase in massecuite viscosity occurs as the crystal contents rise above 40%.

Motor current is a useful indicator of power drawn, but it is possible to purchase a true power monitor that takes account of the variation in power factor of a motor as the load increases.

**Radio Frequency (RF) probes (Radford et al., 1987 and Radford et al., 1988)**

Radio frequency probes were designed to measure the electrical properties of the surrounding fluid at frequencies of around 45 MHz. At this frequency the signal was affected by both the conventional electrical conductance and the dielectric constant. They were designed to provide two outputs, one sensitive to effective impedance and the other to effective capacitance. The result was one signal that was more sensitive to mother liquor concentration and one that was more sensitive to crystal content. A particular advantage of RF probes was that they could tolerate a certain degree of encrustation on the probe without an adverse effect on the reading.
RF probes were used previously at the Tongaat Hulett Refinery to automate pan boiling, but they were prone to component failure due to high operating temperatures. The design used is now no longer manufactured.

**Boiling Point Elevation** *(Rozsa, 2013, Saska, 2002 and Mckintosh, 1985)*

The temperature of a solution boiling at constant pressure increases as the concentration of solutes increase. The rise in temperature above the boiling point of the pure solvent (water in the case of pan boiling) is known as boiling point elevation and can thus be used as an indicator of the concentration of the boiling liquid.

Boiling point elevation (BPE) can thus be used as a measure of the mother liquor concentration during pan boiling. It requires stable and accurately measured pressure within the pan. Rozsa (2013) reports that BPE needs to be measured within 0.1 °C accuracy to be able to control supersaturation safely.

Good circulation of massecuite within the pan and careful placement of the massecuite temperature measurement point are necessary to try to minimise superheating effects, i.e. where the massecuite is hotter than its actual boiling point at the prevailing pressure (Foster and Wright, 1962). The level of crystal content can also have an effect on the degree of superheat.

Differences in the response times of pan pressure and massecuite temperature to disturbances can make BPE readings very unstable if pan pressure cannot be held suitably stable (Love, 2002).

**Online Refractometer** *(Rozsa, 2011 and Rozsa, 2013)*

An online refractometer is the most suitable instrument for monitoring the concentration of the mother liquor both at graining and during boiling. Being based on the measurement of refractive index of the liquid on the face of a transparent prism, it essentially replicates the laboratory technique used for measuring liquor concentration, viz. brix. The measurement is generally not affected by crystals present and can therefore be safely used to monitor supersaturation throughout the boiling.

These probes are purchased precalibrated and do not need calibration once installed, relying as they do on a fundamental measurement. Because the probe is only sensitive to a very thin layer of material on the surface of the prism, good circulation of massecuite or liquor over the face of the prism is essential to get both a representative measurement of the contents within the pan and a fast response time. Donovan (1988) expressed concern over the slow response times of pan refractometers, whilst Mackintosh (1985) reported that CSR had settled on refractive index at constant temperature as the most appropriate measure for controlling the process during the graining and grain establishment phases of the batch cycle.

**Configuration of the Pan control System**

Based on a combination of past experience with batch pan automation at the refinery and elsewhere within the Tongaat Hulett group, a review of the literature on pan control and some recent experimentation on a refinery pan, a strategy was chosen on how to proceed with the automation of the refinery pans.

It was decided to give particular attention to pan seeding and to focus on trying to achieve the ideal of “full seeding”. Full seeding is where all all the microscopic crystals added as a seed slurry grow into product crystals and no extra crystals are generated by nucleation
during the seeding process. To assist in achieving this, an online refractometer (K-Patents) was chosen as the primary measurement for controlling the boiling, as it would allow accurate control of the concentration at the seeding point. The seeding procedure implemented, only possible in a stirred pan, shuts off steam supply for a period to allow slurry addition and initial growth to take place in the absence of evaporation. This is a slight variation of the procedure described by Bachan and Sanders (1987).

Evaluating the success of slurry addition at the time of seeding is notoriously difficult. The minute crystals cannot be seen by eye or even with a magnifying glass. Attempts to take samples and observe them under a microscope are also fraught with problems. The high levels of supersaturation, high temperature and rapid crystallisation rate result in small amounts of cooling and evaporation from the sample causing spontaneous nucleation and growth by the time the sample is observed under the microscope. Experienced pan boilers appear to be able to judge the success of the seeding step by the extent or degree of “sparkle” of a sample on a glass slide held up to a light immediately after it has been taken. To provide a more reliable measure, based less on extensive experience of good and bad seeding, the decision was made to install a pan microscope (ITECA) fitted with a video camera and computer software that allows images to be displayed and analysed in the control room.

As an consequence of recent work on the use of cooling crystallisation on white masses (Jensen and Love, 2015), the decision was taken to allow for a period of flash cooling crystallisation at the end of each boiling cycle, allowing higher yields with lower steam consumption.

The pan control strategy that was implemented on the fourth boiling pan at the Tongaat Hulett Refinery is based on the configuration of instruments and standard PID control loops shown in the simplified piping and instrumentation diagram (P&ID) in Figure 1.

Figure 1. Simplified P&ID showing structure of control strategy based on standard PID control loops
The approach followed with this control strategy is that regulatory control is implemented by standard single input single output PID control loops. A high level switch allows a higher level of automation by effectively deciding which of three possible control loops is regulating the feed control valve at any point in time.

As mentioned earlier, the primary signal used for controlling the crystallisation process is the output from an online refractometer. To give an indication of the crystal content within the pan, although only sensitive to higher levels of crystal content towards the end of the batch cycle, an electrical power monitor was fitted to the motor driving the pan stirrer. A power monitor was expected to be slightly more sensitive to crystal content than the more conventional technique of monitoring the current drawn by the motor.

The full batch pan cycle is automated by a "recipe" program that does not do direct feedback control but rather orchestrates the cycle by switching controllers in and out of manual (and setting the appropriate manual valve position when in manual) or by providing appropriate set points for the individual PID control loops.

The Batch Pan Control Recipe

The recipe that orchestrates the full batch pan cycle is shown in Figure 2. The recipe is designed around a set of parameters that can be adjusted to optimise the boiling cycle. A list giving the description of all these parameters is given in Appendix 1.

A detailed description of the batch pan control recipe, broken up into 15 major steps identified by the numbering along the bottom of Figure 2, is provided in Appendix 2.

In summary, the recipe directs the full batch pan cycle through the following steps to take it from start to finish:

- Start raising vacuum in the pan;
- Once there is a reasonable degree of vacuum in the pan, open the feed valve (using the level control loop placed in manual mode) to start filling the pan;
- Once there is adequate level and adequate vacuum, set the steam flow into the pan at a high rate to start concentrating the contents of the pan rapidly;
- When the pan has filled to the required graining level (normally the minimum operating volume, with a level just above the top of the tubes) close the feed valve before placing the level control loop in automatic mode. The level control will then ensure that this level is maintained as the contents are concentrated towards the graining point;
- When the concentration of the liquor within the pan reaches a point slightly below the graining point, slow down the steam flow into the pan to approach the graining point slowly. At this point flush the seed line with water to ensure that is not blocked when seed slurry addition is required;
- When the concentration reaches the setpoint for adding the seed slurry (the graining point), shut the steam valve and the feed valve. Wait for a short period and then add the seed slurry via the automated seed valve;
- Wait for a further period to ensure that the seeding has been successful, using the images from the pan microscope to check that there is sufficient grain. During this period, no evaporation is taking place, and growth is occurring by depleting the existing supersaturation. Because the crystal content and total crystal surface area is very low at this point, the level of supersaturation will drop very slowly with minimal reduction in crystal growth rate. If the seeding has been unsuccessful, the boiling cycle must be interrupted manually and the problem corrected before proceeding. Confirmation of successful seeding will allow the recipe to proceed;
• Sufficient time is then allowed for grain development to proceed without evaporation. The length of this period is chosen to end when crystallisation will have reduced the available supersaturation to a point where the consequential drop in crystal growth rate is significant. At the end of this grain development time the steam flow to the pan is started again at a relatively low rate (to allow for the fact that at the prevailing low crystal content the total crystal deposition rate will be low). The feed valve is placed on automatic with the brix controller controlling the feed with a set point chosen to provide a suitable level of supersaturation to drive crystallisation without the formation of false grain;

• As boiling progresses, the steam flow is ramped up to a maximum value to take account of the increasing crystal content. The brix set point can also be ramped up to maintain an appropriate level of supersaturation as the mother liquor purity decreases;

• During the progression of the boiling, if at any point the crystal content becomes too high (as determined by the power level monitor) the power controller will correct this by opening the feed valve;

• When the pan reaches the full level the brix controller is placed in manual with a closed valve to prevent any further filling of the pan. The steam is left on, to brix up the pan and the set point of the stirrer power controller is set to a value that represents the tightness required at the end of the boiling cycle;

• When the stirrer power signal indicates that the pan is sufficiently tight, the steam flow is switched off and the optional cooling cycle begins;

• To cool the contents of the pan, the pressure in the pan is decreased by ramping down the setpoint of the pressure controller at a rate that is slow enough to not precipitate false grain formation. During this period the setpoint for the stirrer power controller can be ramped up to a maximum level desired at the end of the cooling period. During the cooling period, the feed valve is controlled by the power controller, ensuring that the pan does not over tighten during this final phase of the pan cycle; and

• At the end of the cooling period, the vacuum is broken and the pan can be struck.

The descriptive terms, used in this broad summary, such as reasonable degree, adequate, high rate and rapidly, are quantified explicitly as part of setting up the recipe by choosing appropriate values for the parameters P1 to P26. Many of these values will be specific to the design of the pan being automated or to the grade of massecuite being boiled in the pan.

Performance of the Automated Pan

The implementation and testing of the automatic pan control system required close cooperation between staff from the Technology and Engineering Group and staff from the Refinery.

A critical aspect of the automation project was the installation and testing of new instrumentation, particularly the online refractometer and the pan microscope. Initial advice was that online cleaning of the refractometer would not be required, but this turned out to be essential and was subsequently fitted. The pan microscope has proved enormously valuable in setting up the seeding aspects of the pan control. Work is still progressing on trying to get the features of the automatic crystal sizing working correctly, but this has not been a major focus of the work up till now.
Absolute pressure must drop to P1 before the feed valve is opened to start charging the pan.

Pan pressure must be below P3 to allow steam valve to open.

After the cooling period is complete, vacuum can be broken, the stirrer stopped and the pan can be struck.

Measurement Trends: Blue
Setpoint Trends: Red

When pan reaches minimum operating level, feed valve is closed.

When level is sufficient, start stirrer on high speed.

When level is sufficient, begin feeding steam to calandria.

Steam Flow Ramp Time to allow for slower CDR with smaller grain size.

Seed Valve Open Time for water flush

Wait time to ensure full grain development.

Wait time before confirming presence of adequate grain.

Cooling Time

Steps in Description of "Boiling Recipe"

Figure 2. Graphical representation of Batch Pan Control Recipe
The new control hardware required that all the existing instrumentation and the new instrumentation needed to be wired up to the new system and the pan boilers trained on driving the pan using the DCS control screen and keyboard when operating in manual mode. Programming and testing the control strategy could then proceed whilst allowing the pan boilers to take over in manual mode as and when necessary.

Once it was possible to monitor and record the operation of the pan using the DCS it became evident that the pan boilers were at times adding substantial quantities of water to the pan by using the sight glass washing facility. To ensure that this wash water usage could be properly monitored and to discourage excessive use, an actuated valve was installed. The actuator was connected to the DCS so that it could only be activated from the control panel and thus monitored by the DCS.

The setting up of the recipe required choosing and testing the 26 parameters used to fully define the boiling cycle. These choices were based on a combination of standard practice, fundamental sugar technology, pan boiler experience and a degree of trial and error.

The automatic control of the fourth boiling pan has achieved good acceptance by the pan boilers and is the normal mode of operation for the pan. The system is now no longer critically dependant on operators with extensive experience of pan boiling to ensure reliable results.

The focus of the work on the pan automation has been to set up the pan to provide a system that can reliably and repeatably boil batch strikes with a minimum of manual intervention. This has required attention to the performance of the instrumentation, programming the control recipe and working closely with the pan boilers to build acceptance of the system and to refine the control recipe. The initial evaluation of the performance of the system has been mostly qualitative.

There is excellent repeatability between pan boiling cycles; a primary requirement for a batch pan automation system. Initial evaluation of plant results (MA and CV of product sugar) has not indicated any substantial improvement in sugar quality from the automated pan system when compared with standard manual boiling, but there is anecdotal evidence from the operators of improved pan performance.

The operations staff have reported the following benefits from the automated boiling system:

1. Less vibration on the centrifugal floor from machines processing fourth boiling sugar (assumed to be due to a better quality sugar that purges well in the centrifugal basket);
2. Less breakdown type maintenance on the centrifugal floor due to point 1 (no sensors becoming loose or frequent need to change machine brakes etc.);
3. A reduction in movement water usage on the pan floor from approximately 120 tonnes/day to approximately 80 tonnes/day. This is the total water usage by all five pans and thus represents a substantial reduction if it is all due to the automation of the fourth boiling pan (Pan 5);
4. A reduction in the quantity of direct sugar rejected in the dryhouse due to high levels of moisture (from approximately 8 tonnes/day to zero). This is assumed to be a result of better quality sugar that is easier to dry; and
5. The boiling process is now consistent from strike to strike which makes troubleshooting easier when there are changes in sugar quality. Previously, pan boilers would sometimes skip or forget steps in the boiling procedure, producing individual pan strikes with poor sugar quality.
The qualitative assessment of the performance of the automation has been positive but there is clearly a need to optimise the boiling recipe (by making alterations to the 26 parameters) and to undertake a quantitative evaluation of the benefits of the automation.

Conclusions

A new batch pan control strategy, using modern instrumentation and control hardware has been implemented on a batch pan at the Tongaat Hulett Refinery. The control strategy was designed to be highly configurable with 26 numerical parameters defining the details of the recipe that orchestrates the steps of a full pan cycle. The control strategy has received good operator acceptance and is able to achieve excellent repeatability between batch pan cycles.

Close attention was given to the automation of the seeding aspect of the pan cycle in an attempt to approach the ideal situation of full seeding. This has resulted in a system that is far less reliant on "art" and the need for experienced and skilled operators to achieve acceptable performance.

An unconventional feature included in the batch pan cycle was the ability to provide a period of flash evaporative cooling crystallisation at the end of the boiling cycle. This has worked successfully and allows higher yields to be achieved with lower steam consumption.

A significant improvement in plant measurements of sugar quality has not been achieved with the new control scheme, but it is hoped that future work on optimising the settings of the parameters that define the recipe will yield positive results in this regard.

Acknowledgements

The success of the automation project was in a very large part due to the input of the Refinery instrument staff (Lucky Penduka, in particular) and the support of the individual pan boilers who embraced the system and provided the "art" that was used to help set the parameters which define the detail of the batch boiling recipe.

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APPENDIX 1

The parameters that specify the detail of the batch pan boiling cycle are:

P1 Absolute Pressure at which feeding can begin
P2 Absolute Pressure set point for concentration
P3 Absolute Pressure set point for graining and “building up
P4 Absolute Pressure set point at end of cooling period (at the end of the boiling cycle)
P5 Pan level to allow steam to be fed to pan
P6 Pan level to allow stirrer to be switched on
P7 Pan level set point for concentration and graining
P8 Pan full level
P9 Steam Flow set point for initial concentration
P10 Steam Flow set point for approaching graining point
P11 Steam Flow set point at the beginning of the “Bringing together” period
P12 Steam Flow set point for building up the pan (majority of evaporative crystallisation)
P13 Brix set point to begin slow approach to graining point
P14 Brix set point for graining point
P15 Brix set point at start of the building up of the pan
P16 Brix set point at the end of building up the pan (i.e. when the pan is full)
P17 Seed valve open time for water flush
P18 Stabilisation time after brix reached graining point
P19 Seed valve open time for slurry addition
P20 Wait time before confirming presence of adequate grain (to determine whether manual intervention is necessary or not)
P21 Wait time to ensure full grain development after seeding
P22 Ramp time for increasing steam flow (to allow for “bringing the grain together”)
P23 Cooling time for period of vacuum cooling at the end of the boiling cycle
P24 Stirrer power set point for majority of boiling cycle (to ensure that pan does not “over tighten” during building up of the pan)
P25 Stirrer power set point to define the extent to which the pan is “brixed-up” at the end of the boiling cycle
P26 Stirrer power set point to specify the tightness of the massecuite required at the end of the cooling period which is the last phase of the overall pan cycle.
APPENDIX 2

The pan boiling recipe can be broken up into a number of discrete steps numbered from 1 to 15 as shown in Figure 2 and described below:

1. Start raising vacuum on pan with an absolute pressure set point of $P_2$
   - Pan (massecuite) level controller set to control feed valve via high select switch
   - Brix controller set to control feed valve via high select switch
   - Pan power controller set to control feed valve via high select switch
   - Pan (massecuite) level control set on manual with feed valve closed
   - Brix controller set on manual with feed valve closed
   - Pan power control set on manual with feed valve closed
   - Steam flow control set to manual with steam valve closed

2. When absolute pressure drops to $P_1$, set pan level control set-point to $P_7$ but place the controller in manual mode with output set to 100% (so as to fully open the feed valve).

3. When pan level reaches $P_5$, place steam flow control in auto with set point of $P_9$.

4. When pan level reaches $P_8$, switch on stirrer (high speed). Place the pan power controller in automatic with a set point of $P_{24}$.

5. When pan level reaches $P_7$, set the output of the pan level control to 0% (to fully close the feed valve whilst this controller is still in manual mode) and then change the pan level control to automatic mode (the set-point should remain set at $P_7$). Set the brix controller to auto with set point of $P_{13}$. This is a brix slightly below the graining brix ($P_{14}$) to allow the approach to the graining point to happen subsequently at a slower rate.
   At this point the brix controller will be sending a signal to the feed control valve to stay closed (to allow the pan to concentrate). The level controller will, however, request the feed valve to open sufficiently, when necessary, to prevent the concentration from causing the pan level to drop below the desired minimum value for boiling, $P_7$. The high select function will ensure that the level controller requirement to open the feed valve will take preference over the brix controller requirement to close the feed valve.

6. When the concentration reaches the required brix set-point, $P_{13}$, change the set point of the brix controller to $P_{14}$ (the graining point brix). Change the steam flow set point to the lower value, $P_{10}$, to allow the graining point to be approached more slowly. Change the absolute pressure set point for the pan to $P_3$, the value to be used for the evaporative crystallisation portion of the boiling.

6A. At this point it is important to ensure that the slurry feed line is not blocked. The slurry funnel must be filled with water and a squash ball floated on the surface of the water (The control system is to give an instruction to the pan boiler to do this task). Once this has been done and confirmed by an entry into the control system, the slurry valve is to be opened for a period of $P_{17}$ seconds. Once this has been done, the pan boiler has to check that all the water has been sucked into the pan and to confirm by an entry into the control system that this has been achieved.

7. When the brix in the pan reaches the graining point, $P_{14}$, place the steam flow controller in manual and shut the steam valve. Allow a stabilisation time of $P_{18}$ seconds to elapse to ensure that the brix has stabilised.
8. The pan boiler must now fill the slurry funnel with the required quantity of slurry (200 ml is the required quantity according to the current recipe, but this may be optimised in future) and to float a squash ball on the surface of the slurry. Once this has been done and confirmed by an entry into the control system, the slurry valve is to be opened for a period of P19 seconds. Once this has been done, the pan boiler has to check that all the slurry has been sucked into the pan.

9. At this point, the control system can simply keep track of the time since seeding with slurry. The pan boiler needs to watch grain development and if none appears within a reasonable time, P20 minutes, manual intervention will be required (e.g. re-seeding at the same conditions or concentrating to a slightly higher brix before reseeding) Note that the stirrer must remain on high speed throughout this whole pan cycle.

10. Assuming that the slurry seeding was successful and that no manual intervention was required, wait for a period of P21 minutes to allow for full development of the grain that was added as slurry. During this period, as a result of the depletion of the level of supersaturation of the mother liquor, the brix reading will drop.

11. At the end of this “grain development” time, boiling can recommence. Place the steam flow controller on automatic with a set point of P11. This is a value less than that required for the latter stages of evaporative crystallisation (P12) to allow for the slower crystal deposition rate (CDR) at this stage of the boiling due to the small crystal size and low crystal content at this stage (i.e. to assist in “bringing the grain together”). Set the brix controller set point to P15 and begin ramping this set point up to the value P16 required when the pan is full. This ramp is not a time based linear ramp, but rather a linear ramp driven by the change in level from P7 to P8. This ramp is to take account of the changing solubility brought about by the drop in purity of the mother liquor as the pan cycle progresses.

12. During the “bringing the grain together” time, the steam flow set point is ramped up to a value of P12 over a period of P22 minutes. The pan will continue to fill due to the automatic feeding regulated by the brix controller. If the brix set point is relatively high and the rate of crystallisation is high enough (relative to the rate of evaporation) to prevent the brix set point from being reached, the pan will begin to tighten up, despite it not being full yet. At this point the pan power controller will come in to play and will act to add feed and allow the pan to continue filling whilst crystallising.

13. When the pan reaches the full level, P8, set the Pan brix controller to manual and set the output to zero to close the feed valve. The steam is left on to allow the pan to “brix up”. Set the set point of the power controller to P25, the value that will give the desired level of tightness at the end of the boiling portion of the pan cycle.

14. When the stirrer power reaches the required set point, P25, shut off the steam to the pan by placing the steam flow controller in manual and setting the output to close the valve. At this point the period of cooling crystallisation can begin. The cooling crystallisation period is to last P23 minutes. Over this period, ramp the pan absolute pressure set point from its current value of P3 down to the required value at the end of the cooling period, P4. To allow for further tightening of the massecuite in the pan to the consistency required at strike, also ramp the set point of the pan power controller from its current value, P25, up to the value required at the end of the cooling period, P26.

15. At the end of the cooling period, the vacuum can be broken, the stirrer stopped and the pan can be struck.