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BATCH PAN CONTROL BY MICROWAVE BRIX

By

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Abstract

FOR MANY decades, the massecuite brix in vacuum pans has been controlled using simple and cost effective conductivity probes. Despite their widespread use, they suffer from a variety of problems, including temperature sensitivity and changes in impurity loads. Arguably, conductivity probes are not highly process relevant, since they deliver at best only an indirect measure of fundamentally important process variables. This paper presents results from a series of industrial trials using a microwave-based instrument. It presents an overview of the installation and use of this class of device for effective batch vacuum pan control. Experimental results from a series of trials run on a 100 tonne batch vacuum pan are presented.

Introduction

For many decades the Australian raw sugar industry has employed conductivity-based sensors to elucidate the condition of boiling massecuites, in order to control batch and continuous raw sugar vacuum pans. Despite their advantages of low capital cost, ease of installation, and low maintenance requirements, conductivity probes are influenced by many factors that often confound their effective use.

The practical goal of a conductivity sensor is to deliver an estimate of the massecuite 'weight' or 'heaviness' in a pan, so that pan boilers can relegate pan control to a process control system. This gives them the ability to monitor the entire pan stage, without having to attend each pan individually.

Massecuite 'weight' and 'heaviness' are in fact qualitative terms describing the crystal content of the material in the vacuum pan. It is the massecuite crystal content that determines the total surface area available for sucrose deposition. Sufficient crystal surface area (i.e. 'heaviness') leads to a situation whereby the molasses oversaturation cannot feasibly reach levels necessary for secondary nucleation. This buffering effect allows the operator to set the process controller to a reasonably productive level of operation, without fear of filling in the massecuite with secondary nuclei.

Other sensors have been evaluated as possible alternatives to conductivity control (Miller and Skippen, 1989), but the main conclusion was that they were ill suited to the task or prohibitively expensive.

While conductivity-based process sensors are sensitive to changes in massecuite crystal content, they are also sensitive to a variety of other confounding process variables (Wright, 1984), making the level of control suffer. It is therefore desirable to employ a sensor that is more closely related to massecuite crystal content.

The relationship between massecuite crystal content and Brix can be summarised in the following equation.

$$CC = \frac{100\left(Brix_{massecuite} - Brix_{molasses}\right)}{\left(100 - Brix_{molasses}\right)}$$

where

$CC =$ crystal content, % on massecuite

$Brix_{massecuite}$ = massecuite brix

$Brix_{molasses}$ = molasses brix

If the molasses Brix lies within a reasonably small range, then a strong correlation exists between massecuite Brix and crystal content. If the molasses Brix were monitored, using a process refractometer, a highly accurate determination of crystal content should be possible. As such, controlling massecuite Brix is an excellent surrogate for crystal content control.

Factory trials

The following sections detail experiments carried out in a 100 tonne batch vacuum pivot pan, which executes a second seed strike, cuts out 50 tonnes of massecuite to another pan on the stage and then runs up a 100 tonne A strike. This pan is located at CSR Mills Group's Macknade Sugar Mill.

Proposed microwave Brix-based vacuum pan control scheme

An alternative vacuum pan control scheme is proposed, in which the massecuite Brix is controlled by manipulating the fresh liquor feed flow rate to the pan, pictured below in Figure 1. This control loop replaces that of the traditional conductivity controller and has been previously reported (Schneider, 2003). Steam flow control is identical to that employed by the standard conductivity-controlled case.

Monitoring massecuite Brix

Measuring massecuite Brix was accomplished using a pro/M/tec[1] microwave density unit. This system is composed of an evaluation unit that transmits microwave energy between two rod-shaped antennae of 100 mm length, separated by a 100 mm gap, to create a microwave field. Dipolar water molecules have a high dielectric loss at microwave frequencies, leading to signal attenuation and phase shift in the field. In the present system, the attenuation and the phase shift are inversely proportional to the Brix of the media, and the unit can be calibrated across arbitrary Brix ranges.

[1]pro/M/tec Theisen GmbH, Pforzheimer Str. 162, D – 76275 Ettlingen, Germany. (http://www.pro-m-tec.de)

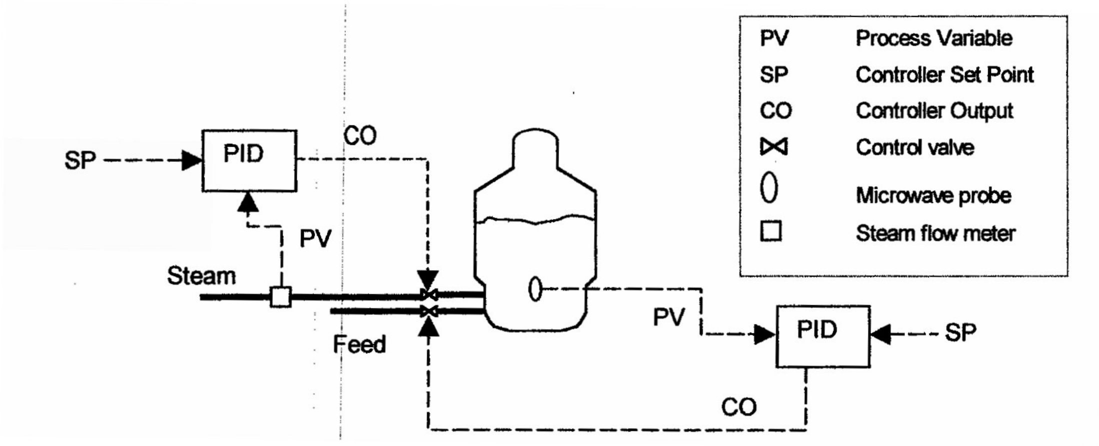

Fig. 1—Schematic of factory batch vacuum pan control system.

The recommended installation of the pro/M/tec is on the wall of the pan, just under the calandria (where a level transmitter would typically be installed). While this location was initially employed, it was soon abandoned due to a lack of dynamic response and non-representative sensing.

The microwave device was instead flange-mounted onto an *instrument tower*. The concept of the instrument tower resulted from the requirement to locate pan sensors in a more representative location, so that they are exposed to circulating material. In this application the instrument tower was located within the centre-well of the pan, flange mounted to the central cone of the pan floor, along the axis of the pan. Figure 2 shows a schematic of the instrument tower, including one of a number of flange mounting pads, upon which a variety of sensors can be placed. The microwave device can be seen mounted onto the topmost pad. Note that the microwave sensor, but not the antennae, is located *within* the instrument tower, which is actually located *outside* of the pan volume.

Access to sensors installed within the instrument tower is a key limitation of this concept, since the microwave Brix device is not reachable, without first shutting down the pan and gaining access to the interior. However, the benefit of this scheme is significant, since the process sensor is exposed to fresh, circulating massecuite. It is worth noting that despite the harsh environmental conditions, the pro/M/tec device ran in this location, without incident, for three crushing seasons.

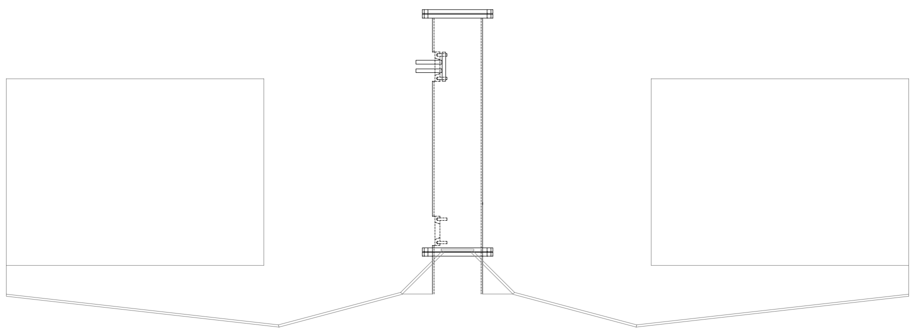

Fig. 2—Schematic diagram of the instrument tower employed in the factory studies.

Typical calibration data for the pro/M/tec device is shown in Figure 3. A linear relationship shows a reasonable fit to the data.

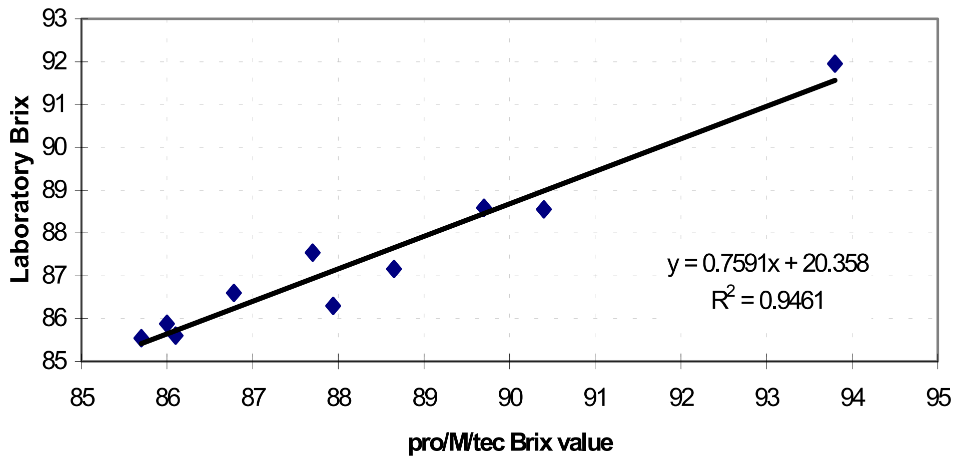

Fig. 3—Calibration data for pro/M/tec microwave Brix device.

Controller development and implementation

Feedback control of the Brix signal was prototyped using UNAC (now known as ProcessACT[2]). A portion of the UNAC controller schematic is presented in Figure 4, indicating its graphical nature.

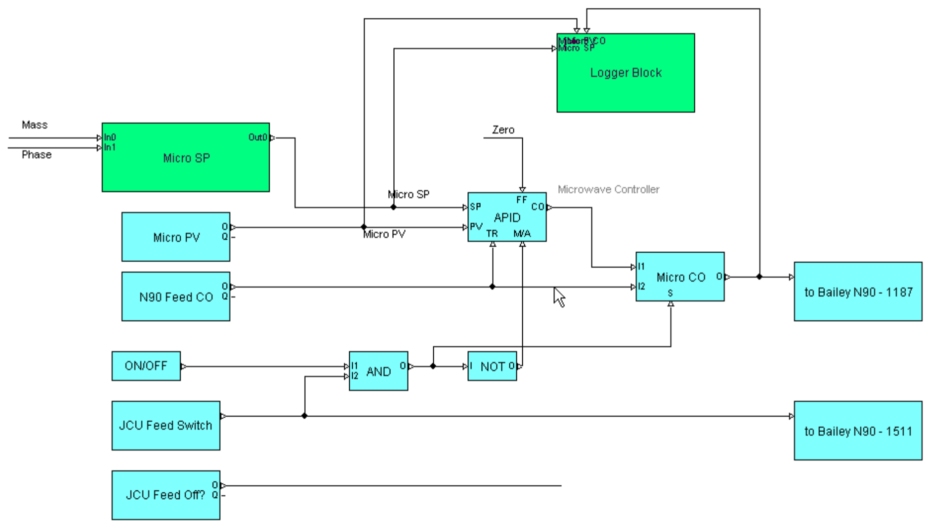

Fig. 4—Brix controller prototype UNAC schematic.

UNAC was interfaced with the existing distributed control system (DCS) in such a way that candidate controllers could be implemented without risk to the process. Bumpless transfer between the two systems was achieved by forcing the UNAC advanced PID controller (APID) to track the feed control valve signal (N90 Feed CO) while it was in manual mode. In order to further 'bullet

[2]Matrikon, PO Box 516, Mayfield NSW 2304 Australia. (www.matrikon.com)

proof' the system, a UNAC-generated 'heartbeat' (actually a square wave with period of 10 seconds) was sent to the DCS. If this signal did not change – indicating that UNAC has frozen or 'died' - the DCS would react by ignoring the UNAC control signals.

Since UNAC has a variety of ready-made blocks, a number of controller prototypes can be quickly developed and analysed. Furthermore, UNAC can easily communicate with a variety of commercially distributed and PLC-based control systems, making prototyping relatively straightforward.

Brix setpoint selection

As mentioned before, the massecuite Brix is expected to change as the batch proceeds. Therefore, a setpoint trajectory for massecuite Brix is required to effectively control the pan. The vacuum pan under study was a pivot pan that boiled a second seed strike followed by an A strike. As such, two setpoint trajectories were necessary. The massecuite Brix setpoint trajectories were scheduled against the tonnage of massecuite in the pan according to Figure 5. Note that a constant Brix profile is required for the second seed strike, while the A strike requires a constant Brix setpoint followed by a ramped setpoint. This ramp is used to account for the increase in massecuite Brix due partly to the boilback of A-molasses, but more so due to the increase in crystal content of the massecuite which is necessary in order to bring the pan to a point where heavy-up can occur without undue nucleation.

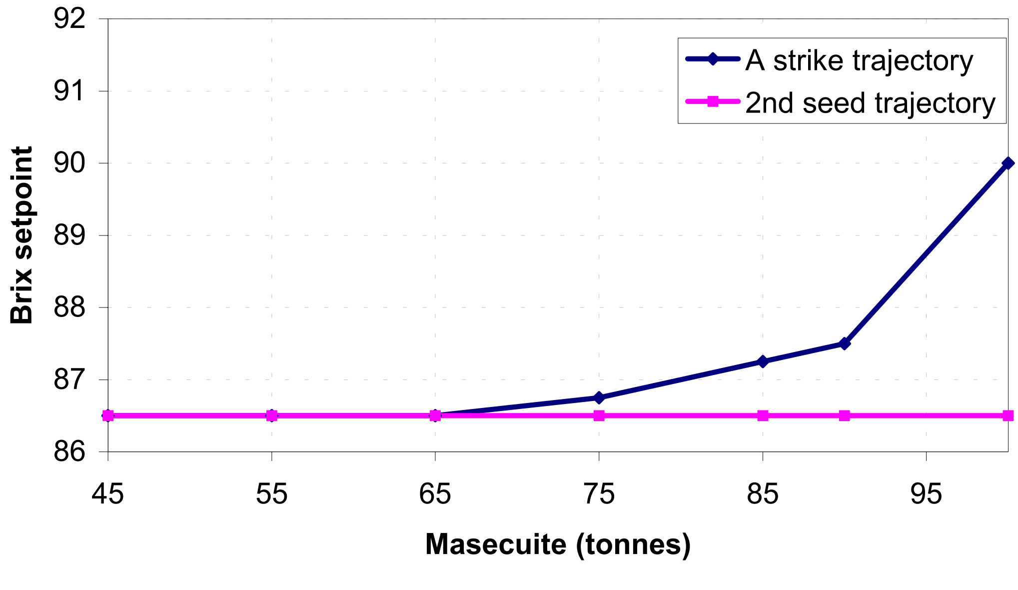

Fig. 5—Brix setpoint trajectories for factory experiments.

The Brix trajectories chosen were based on observed Brix profiles under conductivity control. It should be noted that the setpoint trajectories reported are only of relative significance, since the Brix device was calibrated only approximately. As such, the reported setpoint trajectories should not be considered meaningful in any absolute sense. However, this does not preclude the use of a massecuite Brix device within a closed loop controller.

Controller selection, tuning and performance

A general rule of thumb when designing feedback controllers is to keep things as simple as possible. As such, the first controller tested in the factory trials was a proportional-only controller. When trials commenced it became apparent that this controller could be tuned with very high proportional gains. This result was not surprising, since very high gain terms also worked in a related simulation study (Schneider, 2003). In fact, the gains were high enough such that minimal offset occurred, without recourse to integral control action. The final value chosen for the proportional gain of the feedback controller balanced responsive closed-loop dynamic response against excessive controller action, which would otherwise burden the feed control valve.

Typical closed loop performance of the alternative control system is detailed in Figure 6, which shows a complete cycle for the second seed and A-strike of the pan. The setpoint and measured massecuite Brix are plotted versus the sample time in the batch. The second seed occurs between zero and about the 350th sample time. Cutting of massecuite out of the pan occurs from the 350th to the 500th sample time. The A-strike takes place from the 500th to about 950th sample time. The significant departures of the measured massecuite Brix during start-up and cutting are due to severe temperature departures, due to loss of process vacuum.

During the second seed and A-strike, the control of massecuite Brix is more than adequate, especially considering that a simple proportional controller is being used. Note that the massecuite Brix setpoint is fixed at 86.5 Brix for the first part of the pan cycle, but increases during the second part of the cycle, due to the setpoint being scheduled against the increasing pan tonnage (see Figure 5). One point of interest is that the ramped setpoint trajectory displays a degree of random variation, which is attributed to noise in the measured massecuite tonnage within the pan.

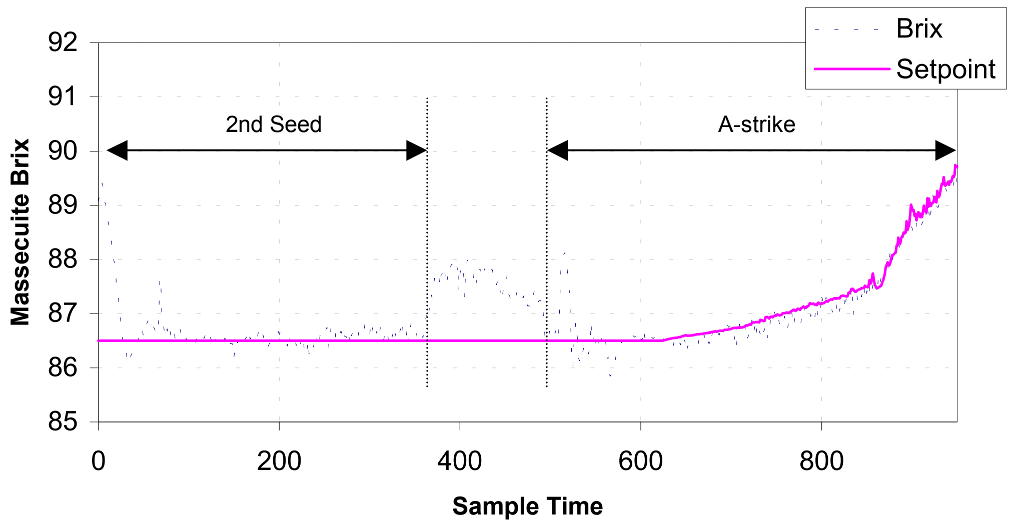

Fig. 6—Control of massecuite Brix in 100 tonne pivot pan cycle.

Figure 7 shows that the feed flow to the pan is similar to that of a conductivity controlled pan strike. It is clear that the control system can maintain offset free control, using a very simple feedback controller.

Compared with conductivity-based control schemes, it is clear that the microwave-based controller is worth consideration in a factory setting. One reason for this is that the massecuite Brix signal is less sensitive to those process variables that influence electrical conductivity. As such, the selection of a setpoint trajectory for high grade massecuite Brix should, in principle, be more reliably than with a conductivity probe. Of course, the temperature sensitivity of the microwave Brix sensor is still an issue, but this could be easily accommodated through a temperature compensation circuit (or a function block in the factory's DCS).

Another important aspect of this scheme was that the pan boilers embraced it quite enthusiastically. In fact, during an episode of high salt levels entering the factory (due to drought conditions in the 2002 season) in make-up water, high salt levels were noted in the feed liquor, making conductivity control impossible (the conductivity readings were off scale). At this stage, the pan boiler requested that the massecuite Brix be brought online, so that at least one pan on the stage did not have to be closely monitored.

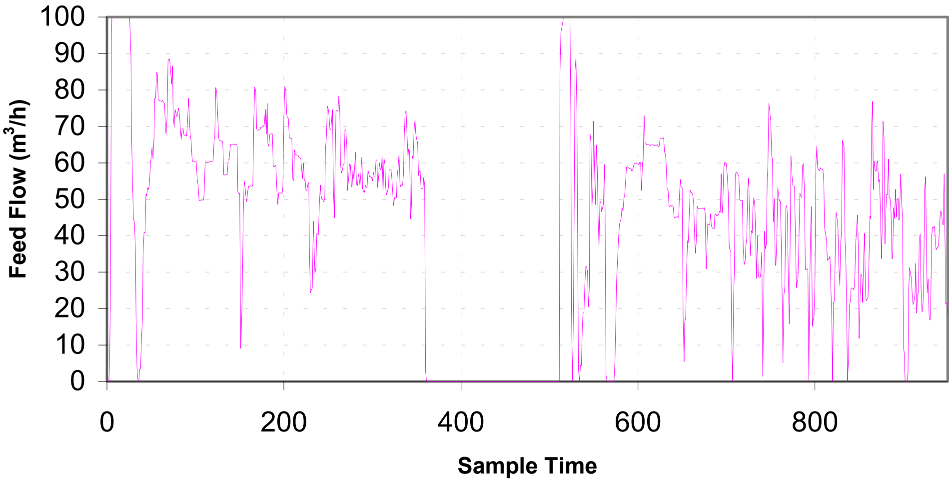

Fig. 7—Feed flow in 100 tonne pivot pan cycle.

Conclusions and outlook

A control system based on massecuite Brix is proposed, in which the conductivity controller is replaced with a massecuite Brix controller. It was shown that this system can be used to inferentially control the crystal content in the massecuite, without having to measure it. A 100 tonne batch vacuum pan was used for a series of plant trials. This pan had an instrument tower within the centre-well of the pan, which enabled the installation of the microwave Brix device (and others) in a location that afforded highly representative sensing. A simple proportional feedback controller was employed to maintain the massecuite Brix along predefined setpoint trajectories, scheduled against the tonnage in the vacuum pan. Operator acceptance of the massecuite Brix control system was encouraging.

Further work needs to be done in order to optimise the control of the pan by massecuite Brix. The setpoint trajectories used were based on the existing conductivity control scheme. Work is currently underway to determine optimal trajectories by computer simulation. Further industrial experiments are recommended.

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