Improving Operational Efficiencies by Automation of the Crystallization Process at Worthy Park Estate Ltd

by

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Abstract

An improvement of Operational Efficiencies in the manufacture of Raw Cane Sugar by Automation of the Crystallization Process is presented. The inconsistencies and challenges of manual sugar boiling coupled with market forces have propelled the urgent requirement to lower production costs and improve on the consistency of product quality. This paper describes the automation of the crystallization process at Worthy Park Estate Ltd. The results of the processing data are then compared to previous data without automation to highlight the gains and benefits. A subsequent discussion that details the improvements of operational efficiencies is also included.

Keywords: Operational Efficiencies, Crystallization Process, Automation.

1.01 Introduction

The success achieved and benefits gained at Worthy Park Factory with the initial automation of the Juice Stream and High Grade Molasses Conditioning in 2001 propelled automation of the crystallization process. Management strategy of the implementation resulted in all four (4) vacuum pans being semi-automated in 2002, for 2003 sugar crop with tactical additions in 2003, for 2004 crop resulting in full automation of the Low Grade Pan.

This automation drive was a systematic implement of the company’s super-ordinate goals, and served as a prelude to the modernization of the High Grade Centrifugal Station. The company’s strategic plans were also influenced by the reality of Low Reducing Sugar to Ash Ratio characteristic to Worthy Park conditions which results in exhaustion difficulties during crystallization.

Preceding the automation, sugar boiling was done by artistic techniques of sugar boilers combined with works aids in the form of simple measurements of temperature and pressure, microscope, statistical and analytical data of the product. It is a fact that there are no two(2) identical artists, and therefore from a consistency standpoint, there was room for improvement by implementing automation of the crystallization process [4]. The installed system has been operational for four (4) years, and a compiled database of data indicates superior results in some areas when compared to four (4) years before automation.

This paper consists of three(3) sections and includes a conclusion, an acknowledgement, and a reference. Section I describes the automation system generally, and particular attention is given to the crystallization control mechanism. Section II provides a concise description Worthy Park’s perspective and aspirations for its motivation to automate the crystallization process. Section III presents an array of results that states clearly the superiority of the automation system. Issues that have arisen in adopting the automation principle are discussed in addition to the effect of abstract conditions such as the polysaccharide contamination in the process stream.
Section I

2.0 Overview of Present Control System

The system that facilitates control of Pan Boiling at Worthy Park Estate Ltd is an interactive Visual Supervisor that is characterized by Data Acquisition, Utilization and Control, Programmable Logic and Supervisory Control. The boiling is controlled primarily by a Local Instrument Network (LIN) Database Control Strategy which is a software program that runs entirely in the LIN Instrument [15].

This running database acquires signals through input cards that are hard-wired to sensors in the plant and processes them in specified ways. Decisions and actions are then made according to the database control strategy and commands to actuators are preformed via output cards [16]. An interactive Graphical User Interface (GUI) complements the LIN Database. Human Interaction with the controlled parameters is possible via this GUI that responds to touch areas [20].

A sub-database of the Main Strategy termed Lin Sequence Database forms the core of the control system that sequences the different stages of the complete Pan Boiling Cycle. It works in conjunction with the main LIN database and interacts by reading and writing values to specified database fields [13]. The strategy in the LIN Database complements alarm conditions, interfaces for adjustment of process parameters, trending and real time display of process parameters. The Database Strategy consists of LIN Blocks that are soft wired to the Input and Output (IO) Cards that are arrayed by slots on racks which are addressable by nodes. An elaborate communications system that utilizes the Profibus DP1 Communication Protocol complements the total interaction between the LIN Database Control Strategy and the field transmitters and instruments [13], [15].

1.1 System Layout

Figure 1 below shows the typical layout of the entire control system hardware. The LIN instrument used at Worthy Park Estate Ltd is a T800 Visual Supervisor Version 3.3 that consists of a main processing unit that comprises of the GUI, the hardware executing the LIN database control strategy, and IO cards that are hard-wired to an array of field sensory and control instruments.

Acquired field data are sensed from the array of sensory transmitters that source process measurements depending on its application and configuration. These measurements are either Digital or Analog measurements.

Figure 1: Showing Control System Layout
The capability to sense logical inputs is also an inherent feature of this system. The data acquired are processed according to the application design of the LIN database control strategy for Pan Boiling, and instructions are outputted to the control instruments such that specified process parameters are maintained to achieve the desired objectives.

A reliable power supply unit and an alarm paging transmitter complements the system. As process parameters exceed or fail desired set-points, an alarm is paged to the shift engineer for attention and remedy.

Figure 2 below portrays the T800 Layout, employed for the Boiling House operations at Worthy Park Estate Ltd. In addition to the T800 Visual Supervisor, there is a modular IO system. This system consists of an array of IO cards that are arranged on racks. Each rack contains a maximum number of cards based on specification, and an Input / Output Controller (IOC) card that serves as the Central Processing Unit. Each IO card is normally termed a Slave, and has a unique communication address on the rack internal IO bus. The IOC communicates with the slave modules that interface with the sensing and controlling elements in the plant, and an external supervisory unit, the T800 Visual Supervisor. Communications between the IOC of all system racks and the T800 Visual Supervisor is achieved by a Daisy Chain, network that runs on the Profibus DP1 Protocol.

![Figure 2: Showing T800 Visual Supervisor Layout](image)

2.2 The Database Control Strategy

The Database Control Strategy is the application that will normally be designed by a Third Party Configurator such as LINtools 2000, and is executed in the T800 Visual Supervisor. This application reflects the boiling scheme utilized, and is achieved by an interconnection of LIN Functional Database Blocks. These blocks are arranged into seventeen (17) different categories and offer a wide and dynamic range of control system characteristics.

Depending on the specification and design of the application, the blocks may be soft-wired and structured to execute control of the entire sugar boiling process. The extent of control is limited only by the design specification that would normally incorporate management strategies and policies regulating the Pan Floor Operations. Figure 3 below shows a part of a typical control strategy being employed currently at Worthy Park Estate Ltd. It portrays a typical control loop, in this case, the control of the vacuum in Pan #2.

An input is read on an analogue input (AI) channel of the D25.AI3 function block and ranged before its input into the PID function block which drives an output according to tuned
parameters for proportional, integral and derivative computations based on a preset set-point for the vacuum of the pan.

Figure 3: PID Loop for Vacuum Control of Pan #2

The output from the PID block is then conditioned by a rate limiter before output to a control valve that admits water into the #2 Pan Condenser. A trend is also established by the DR_ANCHP function block for analysis. An OR block relays all alarm conditions to the paging unit for plant personnel attention and subsequent remedy.

Figure 4 below illustrates the LIN Sequence Database that controls the sequence for the boiling cycle of the #1 High Grade Pan. Each block shown is referred to as a Step in the boiling cycle. Each step will have Actions that are executed by a qualification. To move in sequence from step to step, a Transition Condition must be satisfied [13]. All fields in the sequence are read from or written to the main LIN database control strategy. Harnessing the dynamic range of LIN function block capabilities, and working in conjunction with the LIN Sequence Database, the boiling controls of all pans were automated to the point where the temperatures of all pans, brix control, all Pan Feed Intakes and Discharge Points were controlled via the T800 Unit.

Figure 4: Showing a LIN Sequence database Structure for Pan #1
2.2 The Graphical User Interface (GUI)

The graphical user interface is a custom user screen that is designed in a third party software that compiles an output for downloading into the target T800 Visual Supervisor. Figure 5 below shows the GUI for monitoring and making changes to Pan #1.

Data fields are read from or written to LIN variables in the database control strategy via touch sensitive areas, text write areas and control push buttons. The screens can be so arranged that it mimics by design an operator panel for required operations of Pan #1. These include process parameter display and set-point changes. Similarly, operator panel screens for all Pans and its associated operations can be created and linked to variables in the LIN database thereby giving desired control over all parameters within the boundaries of the application design.

All control instructions that are given in real time are based on the Proportional, Integral, Derivative (PID) computations for an acquired process value of the controlled variable.

2.3 Boiling Control Description

In a typical boiling cycle of High Grade Sugar at Worthy Park, levels for Footing and Finished volumes, are set by a Process Personnel that are prescribed by the established Boiling House Policies. The cycle begins by selection of whether to boil a footing, or a strike, see Figure 5. The admittance of the feed volume required to complete a strike or footing, using syrup or a combination of syrup and molasses is determined automatically by a variable Radio Frequency (RF) inferred brix profile[16].

The sequence of events that monitors the cycle is controlled from the database control strategy and guided by a unique sequence for the vacuum pan, and its associate grade of sugar being boiled. Figure 4 lists the steps that must execute in order to accomplish the crystallization of raw cane sugar crystals in the high grade vacuum pan.
During charging, respective volumes of characteristic feed material will be selected based on purity value, and will transit to the next step when a prescribed level is attained. A check is perform to investigate for false grains after which boiling commences. The method of controlling the feed, during the Boiling Cycle follows variable profile of RF measurement as shown in Figure 6. The objective is to achieve *tightening* by increasing the RF inferred brix value of the massecuite with a corresponding increase in level of the pan.

When the correct finished level of the pan is attained, the pan either strikes or is cut over to prepare for another boiling sequence that is naturally determined by the Boiling House Program.

![Figure 6: Showing Boiling Profile of Pan #1](image-url)
Section II

6.0 Why Automate? A Worthy Park Perspective

Exhaustion during the crystallization process is defined as the recovery of sucrose thereby effecting a reduction in purity termed purity drop of the mother liquor. With its current physical plant and infrastructure, coupled with low % reducing sugar / ash content ratio, purity drops shown in Table 1 were considered acceptable. The purity drop comparison shown in Graph 1A reflects clearly the losses incurred by the factorys operation, of which the crystallization process forms a major component.

Table 1: Showing Characteristic Purity Drops

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Purity Drop</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Massecuite</td>
<td>A Molasses</td>
<td>20</td>
</tr>
<tr>
<td>B Massecuite</td>
<td>B Molasses</td>
<td>22</td>
</tr>
<tr>
<td>C Massecuite</td>
<td>C Molasses</td>
<td>27</td>
</tr>
</tbody>
</table>

It is imperative that we establish precisely why automation of the crystallization process is so crucial to our sustainability noting the current times. Figure 7 establishes thirteen (13) critical factors that determine the exhaustion. Automation of the sugar boiling process has enabled Worthy Park Estate Ltd to achieve control of seven (7) variables whilst four (4) are dimensioned by raw material characteristics, and two (2) are mechanical considerations. Therefore, in automating the crystallization process, the company was able to remove some subjective elements from the final product quality therefore improving overall on its exhaustion, particularly on the High Grade Massecuite as shown in Graph 1A. The foregoing also indicates an increase in efficiency of operation, since the objective of recovering more sucrose in less operating pan time was achieved.

Figure 7: Showing Critical Factors that affect Exhaustion of Massecuite in the Crystallization Process


3.1 Analytic Considerations

3.10 Exhaustion

*Exhaustion of the mother liquor*, the criterion used to evaluate the amount of crystals of sucrose recovered as a percentage compared to the sucrose available, is quantified by Equation 1. Typical reference values from the South Africa Sugar Industry are 68, 65 and 55–60 % for the A, B and C Massecuites respectively, See Graph 8 [12].

Using Equation 1, the purity drops of the A, B, and C massecuites were parameterize to evaluate the effectiveness of the automation relative to the reference values.

\[
E_M = \text{Exhaustion of Massecuite} \\
P_M = \text{Massecuite Purity} \\
P_m = \text{Molasses Purity}
\]

3.12 Crystal Content

Crystal Content which is defined as a percentage mass of Crystal to mass of Massecuite is given by Equation 2.

\[
C_M = \text{Crystal Content of Massecuite}
\]

The fact that automation will allow us to control a majority of the exhaustion factors was a clear indication that the we will be able to maximize within the boundaries of our present plant the maximum possible crystal content. This is reflected clearly in Equation 2 from which, it was inferred that more crystal mass translates equally to an increase in net weight of the final product. The foregoing fact is based on similar conditions being evaluated without the automation implementation. In addition, based on theoretical projections, it will allow us to achieve the percentage crystal mass referenced from the South Africa Sugar Industry, as confirmed in the results shown in Graph 2.

3.1 Purging Efficiency

Purging Efficiency is defined as the measurement of impurities removal that has been achieved during the centrifugal operations. Equation 3 states a relationship that quantifies purging efficiency:

\[
P_M = \text{Purging Efficiency}
\]
PE  =  Purging Efficiency  
PS  =  Sugar Purity.

Any improvements gained by automation will impact significantly on the quality of the final product being sold to the preferential markets since there are premiums and penalties attached. Naturally, it is the absolute objective of Worthy Park is to harness all possible premiums to the collective price paid for its product, thus the need to explore all avenues of maximizing product quality.

4.0  Super-ordinate Aspirations

Despite the challenges that Third World Manufacturing Entities confront, whether political, social, environmental or economical, it is the natural objective to attain a modus operandi To make the best quality product at the least possible cost The forgoing principle encompasses all aspects of all manufacturing processes, to which there should be no exceptions. In the manufacture of raw cane sugar, it is the likely objective to reduce on production and operational costs. This is not a new theory as it has been incorporated worldwide, and the backbone of this revolution is advances in technology. Therefore, it is not strange that Worthy Park Estate have emulated in part what is already established in not only sugar factories, but many other manufacturing processes around the world. In context, automation of the crystallization process at Worthy Park Estate will take this company a step closer to the overall super-ordinate objection of having an entire raw sugar manufacturing operation that makes the best quality raw cane sugar at the least possible cost.
Section III

5.0 Results

In order to indicate the effectiveness in terms of improvement in the crystallization process, data from four (4) years preceding the automation was compared to four (4) years after the automation. Exhaustion Data for the above mentioned period is shown in Graph 1B.

Purity Drops shown in Graph 1A reflects clearly the losses incurred in factory operations before automation. A major contributory factor for the poor exhaustion with the C Massecuite Boiling was due to the abnormal levels of Polysaccharides whose detriment was more pronounced than Starch and Dextran. This phenomenon was observed for about 50% of the cropping time in 2003-2005 and to a lesser extent in 2006.

Graph 2 shows the crystal content improvement in yield by automation of the crystallization process. The decrease in yield of crystal mass from the Low Grade strikes are also attributed to the fact the compounded problem of polysaccharides. These relationships are shown in Graph 3.
and 4 below in which, Graph 3 illustrates a comparison of purity drop from syrup to final molasses, four (4) years before and after automation. Purity Drops of 53.00 and above are considered excellent. Graph 3 shows a reduction in average exhaustion which may mislead the actual improvement of the automation due to the problems encountered with polysaccharides. Graph 4 shows exceptional exhaustion before the polysaccharide phenomenon that occurred about midway of the sugar crops of 2005 and 2006.

**Graph 3: Purity Drop, Syrup - Final Molasses**

Automation of the crystallization process has impacted also on the affined colour of the centrifuged crystals. A comparison of average affined colour IU for an eight (8) year evaluation period is shown in Graph 5 below. The actual results of the automation are more significant since the above includes the colour increases due to the polysaccharide problem during sugar crops.

**Graph 5: Showing Affined Sugar Colour IU**
Graph 6 illustrates the effect of polysaccharide on the affined sugar colour.

Graph 6: Polysaccharide effect on Affined Sugar Colour

Our automation strategy as mentioned earlier included the installation of modern High Grade Batch Centrifugals. An important change resulted in a shift from a four(4) boiling scheme to a three(3) boiling scheme in the boiling strategy [12]. The ultimate objective was the quality of the final product, and the purging efficiency factor was used to evaluate the effectiveness of the installations as shown in Graph 7.

Graph 7: Improvement of Purging Efficiency

6.0 Gains and Benefits

With the advent of automating the crystallization process at Worthy Park Estate Ltd, we have observed the following gains and benefits:

• Low Grade granulations are of a better quality compared to those marred by subjective pan boiling.

• The ability to change from a four (4) boiling scheme to a three (3) boiling with consistent and increased exhaustion results as portrayed in Graphs 1, 3, and 4.

• Boiling of strikes consistently with a specific brix profile for each pan, that contributed significantly to an improvement of sugar quality produced.
• Consumption of less energy attributed to pre-defined boiling sequences, increased throughput and a fixed boiling profile as stated above.

• Pan floor job evolvement that encompassed automatic valves, auditory and visual notifications of events, reduced manual labour input and consequently, increased morale.

• The automation has enabled us to reach standards established by technological advance sugar industries such as the South Africa Sugar Industry as shown in Graph 8.

6.1 Sustaining Crystallization Automation - Discussion

Following four (4) fruitful years of our automation, our experience with this new vehicle embedded into our operations had its fair share of initial issues. We have resolved and have implemented routine procedures to ensure efficient operation of our automation system which are discussed as follow.

The Radio Frequency measurements which are inferred as brix had issues with consistency. A subsequent investigation revealed that the probes were coated with Massecuite which impaired the accuracy of the measurements. This was countered with regular boil out of the pans. Also for effective RF Control, a routine to establish consistent grain size and footing level was implemented. In addition, the ash content is monitored at regular intervals to adjust RF set points.

An indication of increased viscosity, and gumminess normally results with the advent of Polysaccharide contamination about mid crop. The adverse effects of this phenomenon were alleviated to an extent by reducing the RF set-point, and by increasing on the purities of the B and C massecuites.
7.0 Conclusion

Automation of the crystallization process has improved the operational efficiencies of Raw Cane Sugar Manufacture at Worthy Park Estate Ltd. The results have indicated, in addition to increased productivity, an array of operational improvements that impacts on overall efficiencies positively.

With the application of an automated control system (Eurotherm T800), all data collected for production in the Boiling House at Worthy Park Estate clearly indicate that there is greater exhaustion of mother liquor in the high grade strikes, increase in crystal content improved affined colour and purging efficiency, which infers increased unit productivity of operations.

The presence of consistencies in operations of the batch processes has also resulted in further improvement of the overall efficiencies and has impacted significantly on the energy economy, and manufacturing costs of operations at the sugar factory. The foregoing evidence confirms that the implementation of automation has improved the operational efficiencies at Worthy Park Estate. From a purely analytical position, the output yield has met and far surpassed the expectations of management.

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9.0 References

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