Optimisation of White Sugar colour management through the utilisation of on-line colour cameras

Craig Parker, Robert Howe, Brian Black, Carlton Haynes and Catherine Bouché
British Sugar plc and ITECA SOCADEI

Abstract

Ensuring a factory can produce white sugar that meets the solution colour demands of its customers' is a key focus for any sugar factory operation. Managing the process to minimise the financial impact of those demands is always challenging and the default position tends to be to over wash the sugar, thus allowing for variations within the process as a consequence of reacting to laboratory generated data.

The paper describes the development of an online ITECA colour camera system over a two year period at British Sugar's Wissington factory. The development resulted in a significant reduction in process variability around white sugar solution colour that enabled the solution colour set point to be increased, whilst still guaranteeing the final product remained within specification. This led to a financial saving in energy through a reduction in white centrifuge wash water volumes, as well as a reduction in the volume of recycle of sugar back to the white pans from the white centrifuge station.

The paper describes the various developments of the installation to overcome technical obstacles relating to the system location, as well as development of the camera system itself. It also describes how the camera installation enabled the factory team to identify issues with individual plant items.

Introduction

Even during the very early years in the development of the sugar manufacturing process, the importance of producing white sugar, to gain a financial premium over raw sugar, was well understood. This led to a variety of developments, but it was probably the development of the vacuum pan and batch centrifuge during the first half of the nineteenth century that enabled a real step change in sugar quality to be realised [1]. Today, more than ever in a competitive world market, the need to produce good quality final product is well understood. Solution colour is one of a number of key parameters for any factory operation to manage, if it wishes to produce white sugar of a suitable quality for sale to the variety of demanding customers. Although achieving the correct specification is essential, it is also important that the outcome is achieved in the most cost efficient approach possible.

Over the past 30 years there have been significant improvements in many areas of the beet sugar manufacturing process, right from the quality of the beet grown through to the technology utilised in today's fully automated factories. However, there are still numerous influences within a factory operation that can impact on the solution colour of final product white sugar. Unfortunately, these influences are not always controlled within our desired operating windows and this inevitably leads to variations in processing conditions, which ultimately can reflect through into final product quality parameters.

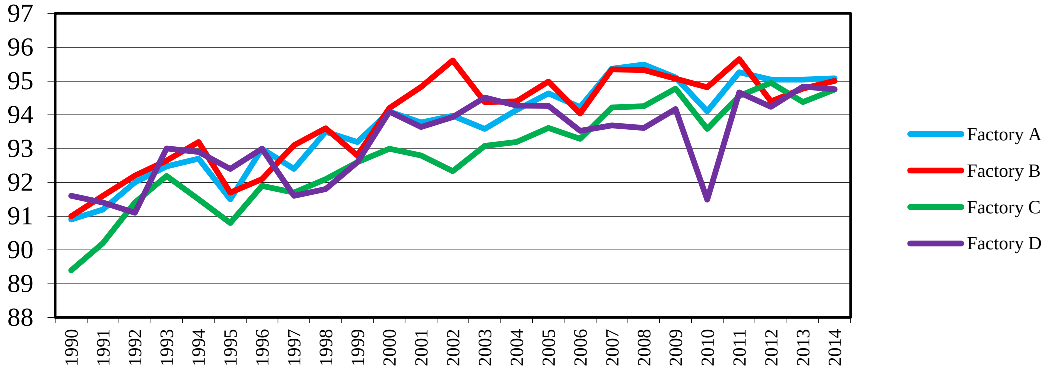
The significant gains realised through developments in the agronomy of sugar beet in the United Kingdom over the past 25 years have led to real improvements in beet quality (Table 1). There have been significant reductions in Amino-nitrogen and sodium content and to a lesser extent potassium. Although the sugar content has not really altered and appears influenced more on a year to year basis by the growing conditions, the overall agricultural impact has been a significant reduction in the quantity of non-sugars passing through factories, as shown by the continuous improvement in thick juice purity over the past 25years (Graph 1).

Table 1 – Beet quality improvements in the UK over past 25 years

Year	Potassium	Sodium	Amino-N	Sugar	Thick Juice Non Sugars
1990	1068	153	181	17.36	8.6
2015	835	70	56	17.25	5.2
% Change	- 21.8	- 54.2	- 69.1	- 0.6	- 39.5

Note: data presented are 3 year averages (i.e. 1990 is average of 1988, 1989 & 1990)

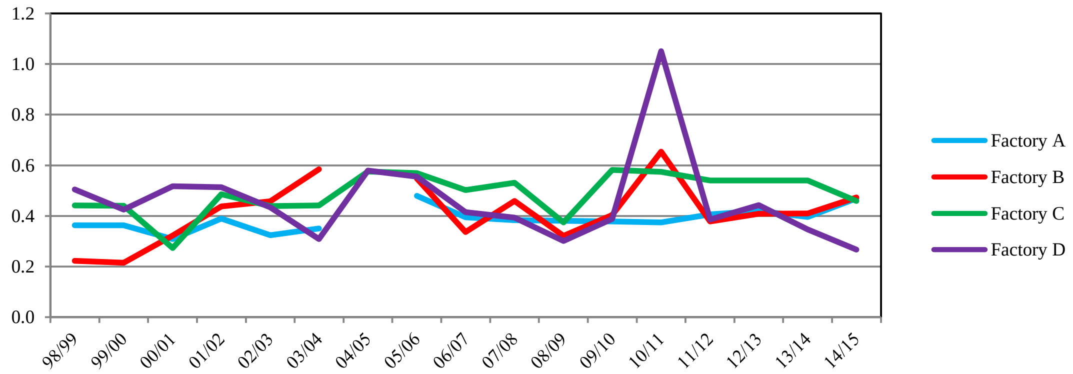
Graph 1 – Thick Juice Purity improvements in the UK over the past 25 years



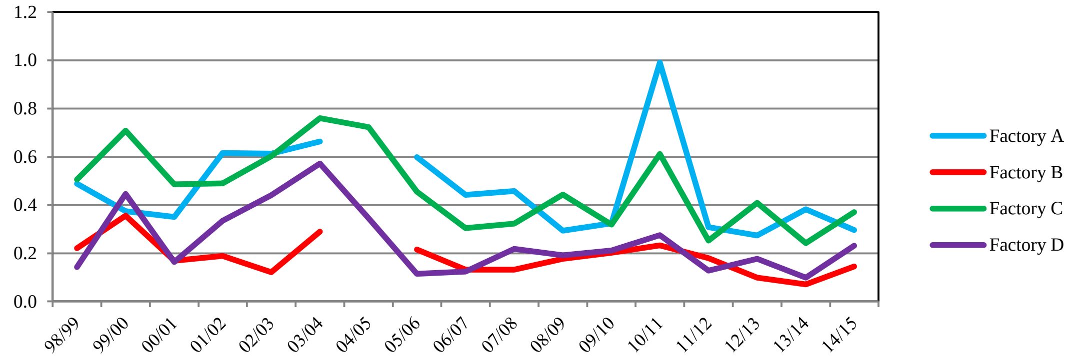
Amino-nitrogen is a key colour precursor compound in the beet process, through its reaction with invert sugars via the Maillard reaction [2]. Any reduction in Amino-nitrogen content will therefore reduce the potential for colour formation within the process and can only be a positive impact.

Over the past 15 years the invert content of sugar beet delivered to British Sugar has remained relatively consistent (Graph 2), whilst the invert generated within the diffuser operations has improved over the same period (Graph 3). Therefore, the colour benefit realised within the process through a reduced level of Maillard reaction activity has been driven by a combination of reduced Amino nitrogen levels in the beet and an improvement in the level of invert created as part of diffuser operations.

Graph 2 – Cossette Invert changes over the past 15 years

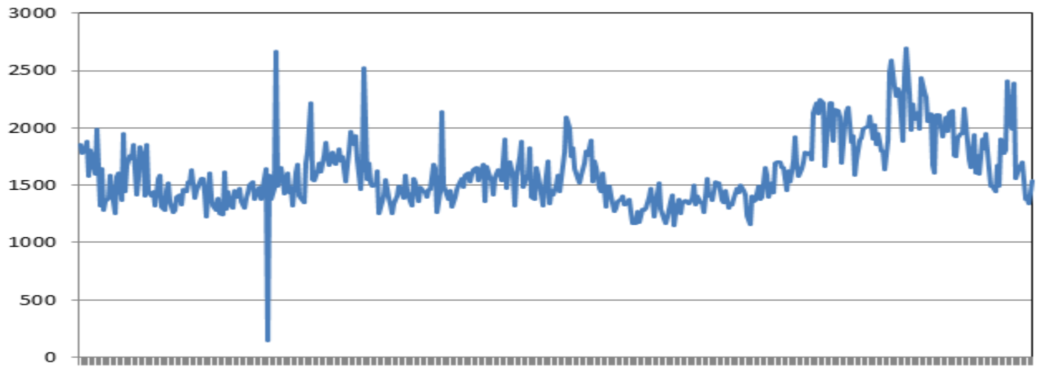


Graph 3 – Invert generated within diffusion operations over the past 15 years



Although beet end colours have generally improved there will always be fluctuations within the beet end process, driven by changes in beet quality entering a factory, process break downs and issues, as well as incorrect decision making by the operators. All these factors come together to create variability to the colour loading that is passed forward from the beet end operations into the sugar end process (Graph 4).

Graph 4 – Thick Juice colour (spot sample every 12 hrs)



The swings in thick juice colour, resulting from variability in beet quality and beet end operation would have a direct impact on the solution colour of the white sugar produced for sale, if no remedial actions were taken. If we assume a white pan elimination of 100 (i.e. ratio between the feed colour into a white pan and the resultant solution colour of the sugar crystallised), then a typical swing seen in thick juice colour of 300-400 ICUMSA units within a 12 hour period would translate into a 3-4 ICUMSA colour variation in the final sugar. Therefore, if we were to disregard all other potential influence on sugar colour, it is clear to see the significant variability that may be present from changes in thick juice colours.

Additional to the impact that changes in thick juice colour will have on the final sugar colour are a number of sugar end influences. These will include variations in colour loading from operational issues around the white pans and white centrifuges. Also, there will be changes in the volume and colour of sugar recycled from the 2nd and 3rd boiling streams (although these tend to be less variable over a short time frame). However, the overall combination of these sugar end influences, on top of the variability already discussed from thick juice will only add to the complexity of trying to optimise the colour of white sugar.

To manage white sugar solution colour British Sugar has traditionally taken hourly spot samples and measured the Reflectance Grade (RG) using a calibrated Anton Paar Sucroflex instrument (originally manufactured by Dr Kernchen), with composite ICUMSA solution colour measurements to check compliance to the required customer and legislative standards. *Note: There is generally a good relationship between ICUMSA solution colour and RG for white sugar, although it does change over time and does require updating periodically. However, the correlation is prone to changes in sugar particle size.*

The main concern with using RG to manage the process is the infrequency of the sampling. Even though the spot samples are taken every hour, there will be several batch white pans dropped and spun through the white centrifuges between subsequent analyses. With little or no other information available to them, process operators are unlikely to make any process changes and therefore the actual ICUMSA solution colour of the final product sugar sent to the silos could change, driven by

- changes in beet end colour
- changes in sugar end recycle colour
- issues with white pan performance
- issues with white centrifuge performance

To provide some security against such fluctuations in processing conditions, factories have tended to run with a margin of safety that takes into account the normal colour variations. This results in an internal colour target below where might be financially optimal, but provides security to ensure the final product is sent to silo within specification.

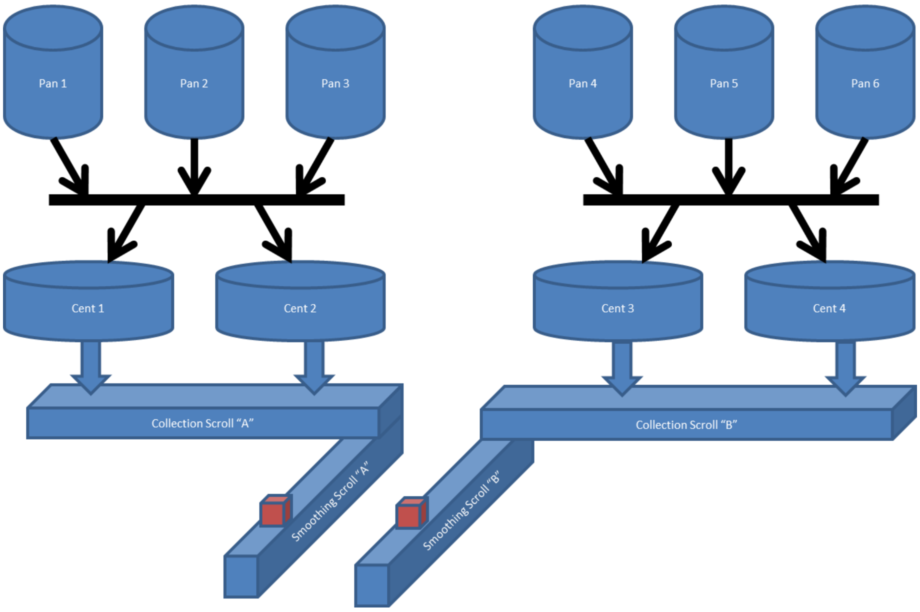
This paper will go on to describe the optimisation of an online colour measurement system, originally supplied by Cybernetix in 2004 and upgraded by ITECA SOCADEI, which delivered an improvement in sugar colour variability and enabled a higher colour target to be set, whilst still ensuring the sugar met associated specification requirements.

Cybernetix colour camera upgrade by ITECA SOCADEI

The original installation consisted of a pair of analogue colour cameras, each camera being mounted on top of a separate smoothing scroll (Photos 1 & 2), with each scroll fed from a pair of batch centrifuges. Three batch white pans fed each pair of centrifuges (Schematic 1).

Photo 1 & 2 – Colour camera mounted on wet sugar smoothing scroll

Schematic 1 – Configuration of white pans, white cents, collection and smoothing scrolls



The aim of the installation was to monitor every batch of sugar discharged from each of the four white centrifuges, as it passed through the smoothing scrolls. The output from the colour camera system would then automatically alter specific operating parameters within the centrifuges to control the colour of the white sugar produced. Specifically this should lead to reduced variability in sugar colour that would enable a higher colour target to be set and realised.

The original camera installation operated satisfactorily for several years and successes were achieved prior to 2010, as reported in a previous paper [3]. However, for a variety of reasons the installation started to malfunction and fail. The analogue cameras became very unreliable and could not be repaired, due to their obsolescence. This was also true for part of the electronic system. It also became apparent that the chosen light source technology was very fluctuant and was leading to measurement instability. All these issues arose about the same time Cybernetix decided to drop this specific line of business and no longer offered a maintenance package for the installation. The various issues with the installation had eroded the confidence developed within the operators for the system. This resulted in them no longer leaving the system to operate in automatic mode (i.e. controlling the centrifuges) and the desired gains around colour management were no longer being realised.

In 2010 British Sugar’s Wissington factory engaged with ITECA SOCADEI, a worldwide acknowledged expert in colour measurement using digital camera technology (Colobserver®, Crystobserver®), to upgrade the existing online sugar colour installation. This paper describes the cost effective solution implemented by ITECA SOCADEI to upgrade the installation, whilst also introducing some new options and features (i.e. automatic detection of non-conformities, video of alarms and automatic control of centrifuge wash timers). A close working relationship between the factory team and ITECA SOCADEI enabled timely resolution of obstacles relating to both the original system and the sugar process itself to be achieved.

After an initial assessment of the existing installation there were a number of technical areas addressed by ITECA SOCADEI. These were:

1. Replacing the analogue cameras (an obsolete technology) with the digital cameras proven within ITECA’s Colobserver® instrument, thus enabling the utilisation of video technology.

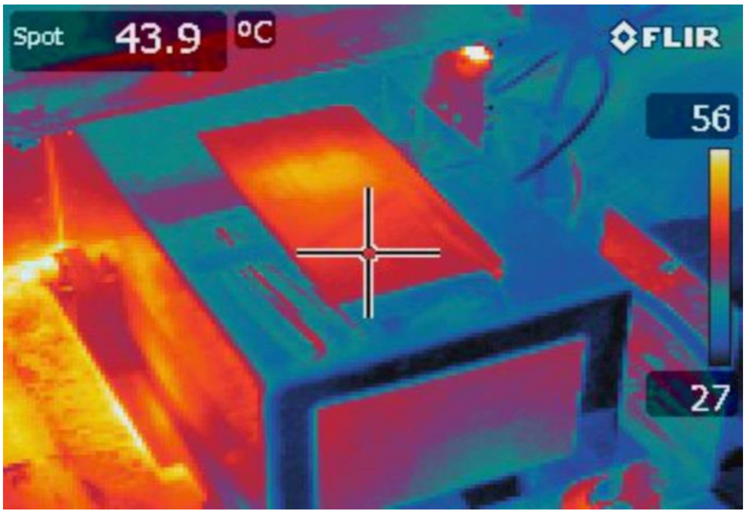
2. Updating the original unstable fluorescent light source technology to a Xenon strobe light source, as successfully and still generally used within the Colobserver®. It was later shown that this type of light source, when used within the original geometry of the Cybernetix installation was causing too many light reflections and was not ideally suited for this particular application. Therefore, the Xenon lamp was ultimately replaced by a LED light source, which had been tested and approved by ITECA SOCADEI during the preceding months. This new light source technology, with a more stable, better focused light and significantly improved life span is now more widely employed by ITECA SOCADEI, especially on scroll applications where it is particularly well adapted.

3. Addressing the issue with the formation of condensation and small deposits of sugar on the housing window that could occur sporadically in relation to process changes. As the level of condensation and sugar developed over time, it increasingly obscured the passage of the reflected light back from the surface of the sugar. This caused drift in the camera output, even though the sugar colour had not altered. A number of change were made to resolve this issue:

- A 250mm spacer was installed between the top of the scroll and the camera housing, thus lifting the camera optics away from the source of the condensation and away from the sugar projections.
- An air heater was added inside the housing to increase the temperature of the existing air knife blowing onto the housing window. The original intention of the air knife was to reduce the volume of warm and damp air making contact with the housing window, with the air being filtered to minimise particles being introduced into the housing area. The introduction of the temperature control was to establish a steady internal temperature and thus reduce the tendency for condensation to form on the camera lens.
- To substantially reduce the amount of steam vapour below the housing window, an air extraction system was installed by the factory team, with extraction points positioned both up and downstream from the camera installation.

4. Improving the calibration stability. The initial modifications described above made a significant improvement to the overall performance of the system with regards to calibration stability and ultimately measurement integrity. However, as the system was always intended to directly manage the wash water addition to each centrifuge, it was essential that there was an even higher level of stability in the overall system. The Perspex window on the bottom of the camera housing continued to experience a level of fogging due to condensation and required a daily clean to remove the condensation, as well as small deposits of sugar. Although the daily cleaning routine did provide a certain level of stability, with respect to measurement drift, there remained a noticeable impact. The solution was to move the calibration tile from within the camera housing, to a new housing that enabled the tile to be inserted below the Perspex window. The introduction of this upgrade was very successful and reduced measurement drift, but a low level of drift was still being experienced. When the tile was moved into position below the housing window it was placed directly into the warm and damp environment within the smoothing scroll. This resulted in a level of condensation forming on the tile, which still impacted slightly on the calibration step. The ultimate solution was to elevate the temperature of the calibration tile, prior to its introduction above the smoothing scroll, thus removing the cool surface and eliminating the formation of condensation. This significant improvement was achieved by the installation of a heating element within the calibration tile housing (Photo 3).

Photo 3 – Thermal image of the calibration tile housing



Following the installation of the heating elements within the calibration tile housing, the whole system and its output became extremely stable. At this point further development was not required to deliver the initial project aim of using the system output to manage the wash water operation on the four individual white centrifuges.

To facilitate the development of the project and to closely monitor the overall performance and progress of the installation, remote monitoring capability along with internet connectivity on the installation was installed. This provided ITECA SOCADEI with real time access to the installation at all times from their facility in France.

Development of the centrifuge auto-washing program

As described earlier in this paper, variation in sugar colour is driven by:

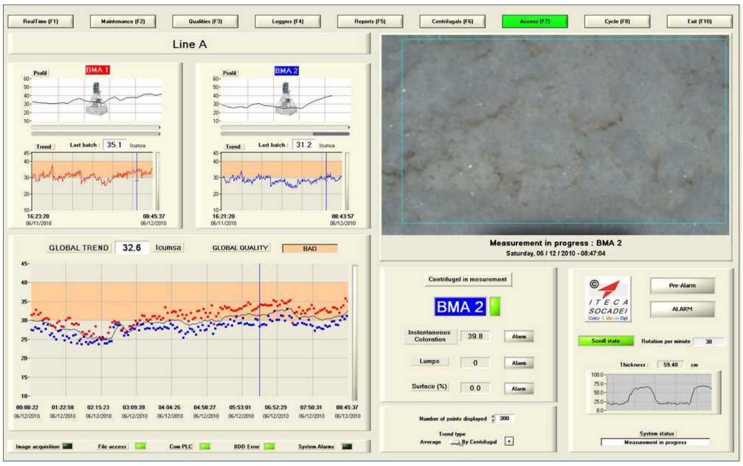
- changes in beet end colour
- changes in sugar end recycled colour
- issues with white pan performance
- issues with white centrifuge performance

These influences, along with the hourly laboratory sugar sampling regime, had led the factory to target a “safe” sugar colour that was a lower colour than desired. However, the lower colour target did ensure that the production sugar met the required colour specification, allowing for swings in colour from the described influences.

Once the development of the on-line colour cameras was completed, their output became totally reliable. The factory was then able to develop a fully automated wash water control system for the batch white centrifuges.

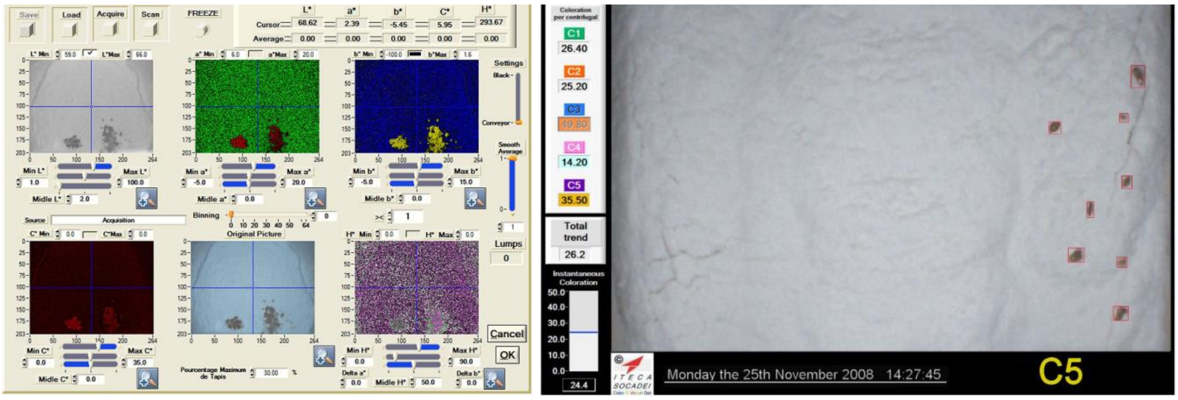
The colour from every batch of sugar discharged by the centrifuges was measured and key information displayed to the operators on the system computer (Photo 4). The data was then used to alter the volume of wash water applied to the centrifuge cycle, thus altering the resultant colour of the sugar discharged in subsequent cycles. The control logic was based on a simple gap controller, where the controller calculated the average sugar colour from the last “X” centrifuge cycles (including the current cycle) and “X” was changeable within the controller program. The controller altered the centrifuge wash timers (i.e. volume of wash water) if the average colour was outside predefined limits from the target colour set-point. The size of change to the wash water timer was dependant on which limit was exceeded.

Photo 4 – System main display



Additional to the rolling average controller just described was the need to manage system failures (e.g. actual colour measured is the same as the previous two actual colour measurements or the change between the actual measured colour and the previous actual colour exceeds a pre-defined limit; out of spec sugar coming out of the centrifuges). Under these circumstances the resultant action would be to send an alarm to the operator, identifying the potential issue. The operator would then investigate the operation of that individual centrifuge. The investigation can be performed anytime as ITECA SOCADEI's software records the video of each alarm that can be visualised on the main screen. Analysing the video of the sugar in the scroll (Photo 5) gives valuable information on the centrifuges operation. For example several little brown lumps of sugar on the surface can indicate that a wash water spray nozzle is plugged or a large surface of really dark sugar can indicate that the plough is not adjusted properly or a wash water spray bar is misaligned.

Photo 5 – Automatic detection of non conformity and its corresponding video



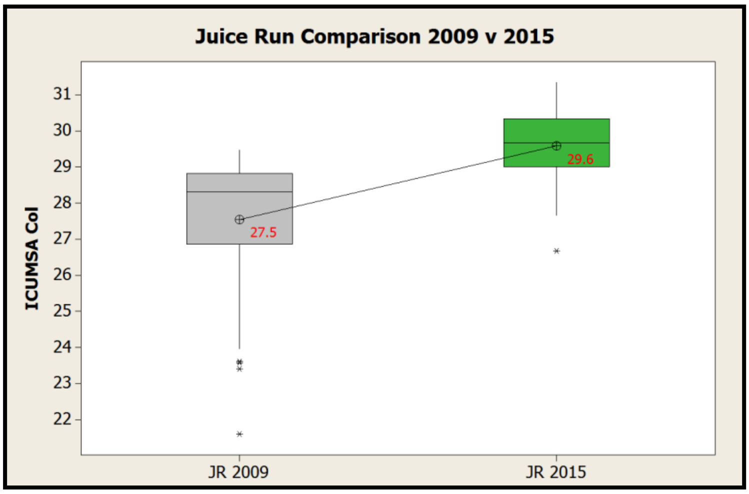
Over time the on-line system became so robust in its performance and the operators were so confident in its capability to manage the sugar colour that they requested an upgrade to the controller program. The change requested was to amend the controller logic to alter the wash timers by only 0.1 second each time, rather than the 1 second changes that was initially used. This further refined the overall performance and reduced over compensation to changes in colour by the controller logic.

One scenario that was not built into the factory's Distributed Control System logic controller was the action to take if the sugar colour exceeded a defined maximum limit. This functionality exists within the ITECA SOCADEI control software, enabling the camera system to initiate a desired action. In this installation when the maximum colour limit is exceeded, a dump slide opens diverting the high colour sugar back to the melter/dissolver and an alarm signal is displayed to the operator. The slide then remains open until the colour measurement returns back to acceptable levels.

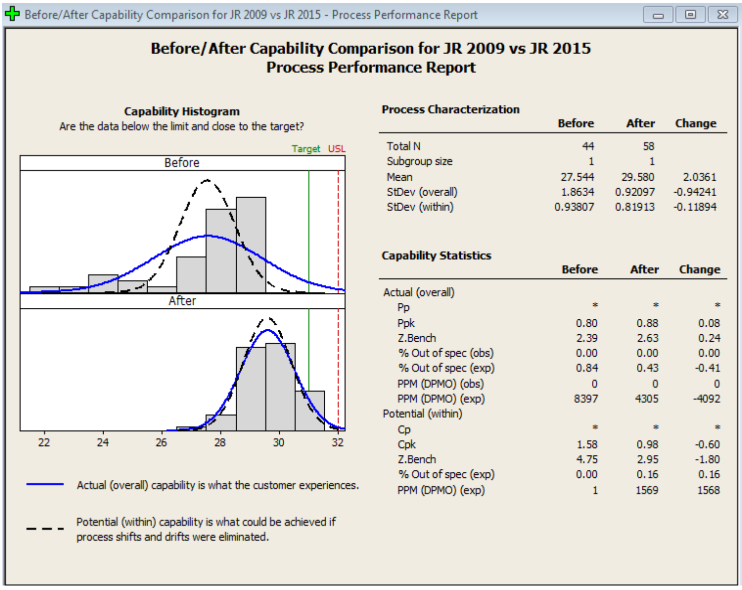
<u>Results achieved using the ITECA SOCADEI online colour system</u>

At the outset of this project the primary aim was to measure online sugar colour that would lead to a reduced variability. This in turn would enable a higher target colour to be set and realised. As can be seen in the data below (Graphs 5 & 6), this aim was indeed achieved.

Graph 5 – Increase in ICUMSA solution colour, with reduced standard deviation before and after the development of the online colour system

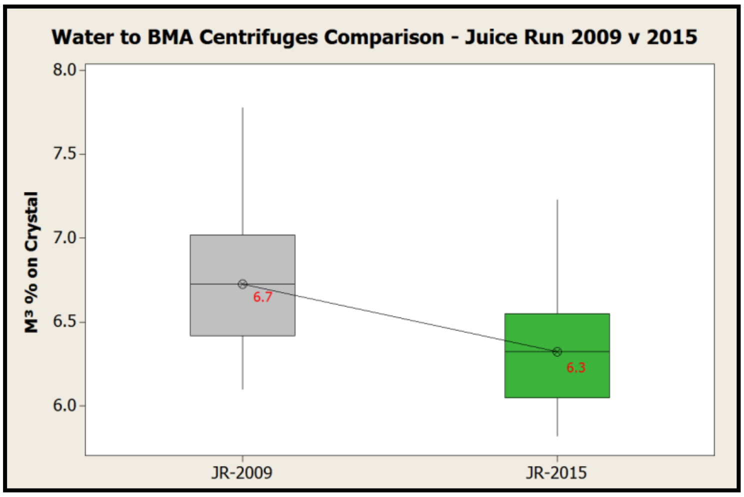


Graph 6 – Process capability comparison, before and after the development of the online colour system

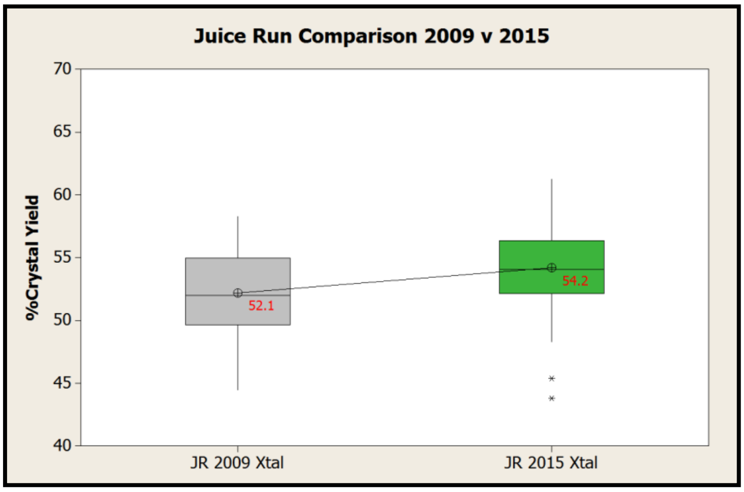


The consequence of increasing the solution colour target was a reduction in total wash water usage to the white centrifuges of $0.4m^3$/hr (Graph 7). This reduction in water usage led to a 2.1% increase in crystal yield, from each batch of massecuite (Graph 8). Additionally, because the control of colour was much tighter, there was a 49% reduction in the number of occasions when high colour sugar was produced that required dumping back to the remelt/dissolver (Graph 9).

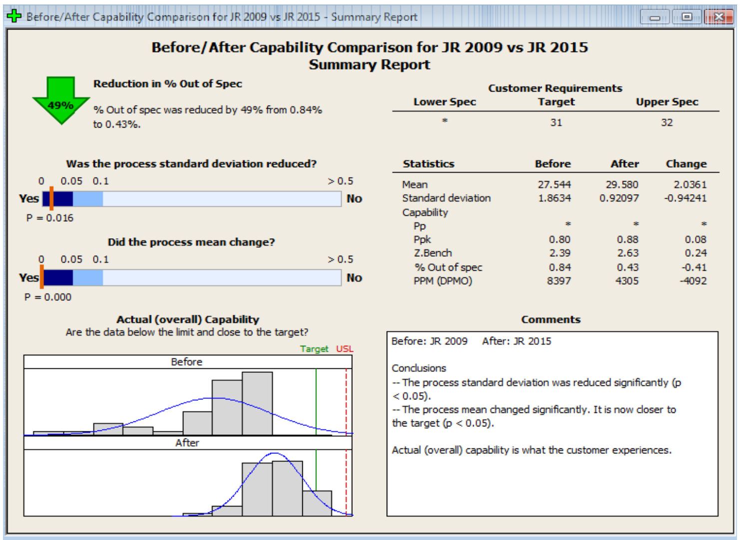
Graph 7 – Reduction in white centrifuge wash water, before and after the development of the online colour system



Graph 8 – Improvement in crystal yield from white massecuite, before and after the development of the online colour system



Graph 9 – Reduction in "Out of Spec" white sugar produced by the white centrifuges, before and after the development of the online colour system



Payback delivered by upgraded system:

The financial savings delivered from the development and implementation of the original Cybernetix installation has been previously reported by Bacon, Black and Curenti [3]. Those savings have not been included in the financial evaluation within this paper.

The additional financial savings associated with the improvement in control of sugar colour, from the development of the camera system described within this paper, have been achieved through the following areas and equate to circa £34.5k/annum:

- Reduction in wash water usage on the white centrifuges, which would require evaporation in subsequent boiling systems (Table 2)
- Reduction in the quantity of "Out of Spec" sugar produced, a significant quantity which would require recycling back to the melter/dissolver (Table 3)
- 2.1 % reduction in the quantity of sugar passing from the white centrifuges through into raw sugar boiling, which would led to a reduction in wash water demand on the associated raw centrifuges (Table 4)

Table 2 – Reduction in wash water usage on white centrifuges

Water usage reduction (m3/hr)	0.4
Water usage reduction (m3/day)	9.6
Juice Run operational days	115
Campaign operational days	180
Juice Run water reduction (m3)	1,104
Campaign water reduction (m3)	1,728
Juice Run Energy reduction (GJ)	2,429
Campaign Energy reduction (GJ) *	1,086
Annual Energy reduction (GJ)	**3,515**
Annual Financial Saving (£) **	**£21,090**

** Pans run on 5th vapour in 7 effect evaporator system during campaign*
*** assumes £6/GJ fuel costs*

Table 3 – Reduction in "Out of Spec" sugar production

Juice Run Daily sugar production (tpd)	1,700
Typical Campaign Daily Sugar Production (tpd)	1,600
Juice Run operational days	115
Campaign operational days	180
Total Juice Run Sugar Production	195,500t
Total Campaign Sugar Production	288,000t
Reduction in "% remelt" production	0.41
Reduction in Juice Run "Out of Spec" sugar Production	802t
Reduction in Campaign " Out of Spec " sugar Production	1,181t
Annual reduction in " Out of Spec " sugar Production	**1982t**

Note: It is difficult to state exactly how much of the "Out of Spec" sugar would actually have been recycled back to the dissolver. The statistical analysis applied to the data states that all the sugar produced above the defined colour limit is "Out of Spec". In reality it is not that clear cut. However, if we assume 50% of this improvement is realised, then the energy saving *associated with the reduction in recycle would be would be 1982 GJ (based on an assumption of 2GJ being required to dissolve and re-crystallise the recycled sugar).*

Financially this would equate to a saving of £11,894 (assuming a £6/GJ fuel cost).

Table 4 - Reduction in wash water usage on raw centrifuges

Reduction in sugar passing forward from white centrifuges	2.10%
Raw cent wash water usage (m3/hr)	1.2
Water usage reduction (m3/hr)	0.0252
Water usage reduction (m3/day)	0.6048
JR operational days	115
Campaign operational days	180
JR water reduction (m3)	70
Camp water reduction (m3)	109
JR Energy reduction (GJ)	153
Camp Energy reduction (GJ) *	68
Annual Energy reduction (GJ)	221
Annual Financial Saving (£) **	**£1,329**

** Pans run on 5th vapour in 7 effect evaporator system during campaign*
*** assumes £6/GJ fuel costs*

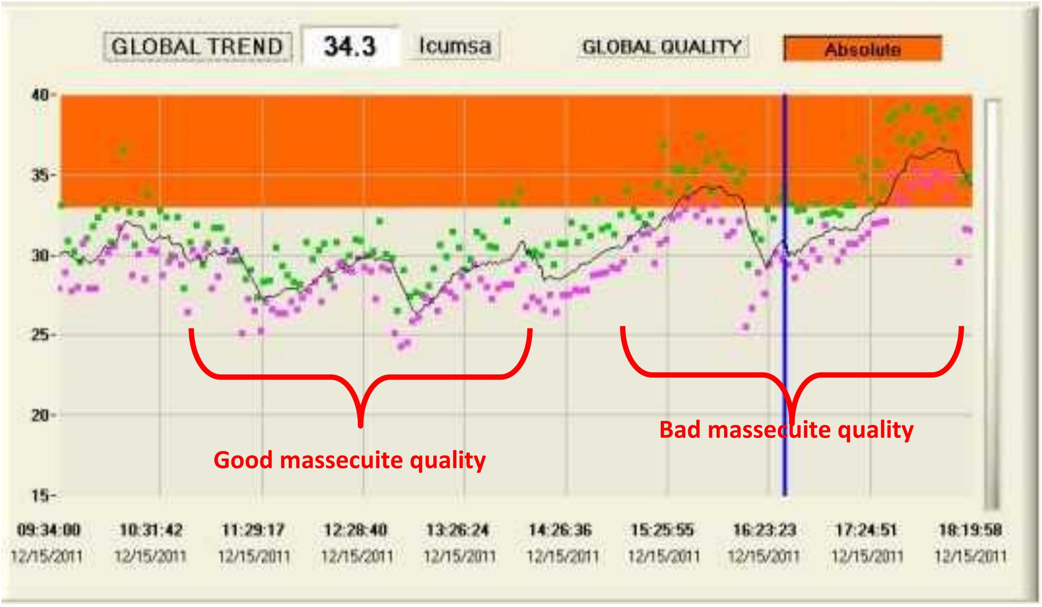
Additional benefits achieved using the ITECA SOCADEI online colour system

Additional to meeting the primary aim of the project, there were other significant benefits realised by the factory team. As this system monitors the performance of each centrifuge, for each batch of sugar produced, it was possible to gain real insight into their operation and indeed the white pans feeding them. The on-line colour system enabled the factory team to quickly identify and resolve the following issues:

- White cent spray bar misalignment leading to bands of discoloured sugar discharging.
- White cent spray nozzle blockages leading to bands of discoloured sugar discharging.

It took longer to identify another issue coming from one of the white pan vacuum transmitters. It was noticed that, although the white pans were fed with the same syrup and the centrifugals adjusted the same way on both lines, the "global colour" on line A and B was behaving differently. Peaks of higher colour were appearing on line A at periodic intervals (Graph 10) while the colour remained very stable on line B.

Graph 10 – Colour peaks due to abnormal massecuite feeding



The consequence of this issue was the control system increased the wash timer on the white centrifuges on line A to reduce the sugar colour back towards target (creating a huge difference in water usage between both lines). These differences were seen periodically post massecuite dropping from a white vacuum pan. This led the operators to consider that something was not correct with the pan control. Indeed, a white pan vacuum transmitter was found 25 mbar adrift from the actual pressure, leading to massecuite of a higher Brix feeding the centrifuge and requiring additional wash water volume compared to other pans. The solution was a simple one: once the transmitter was replaced the measured colour returned to stability and stayed focused on the 30IU colour target.

Conclusion

Between 2010 and 2012 ITECA SOCADEI successfully development an existing Cybernetix colour camera installation from a system that was not delivering the intended duty, into a system that was robust and became an integral part of refinery operations. It enabled the factory team to use the system, as originally defined, to control wash water addition to the white centrifuges in a fully automatic configuration to manage the result sugar colour. The factory operators became so confident in the system's ability to successfully manage the wash water addition, via the auto wash system, that it has been run in auto control for the past three years.

Significant improvements have been made to the variability of colour being discharged from the white centrifuges and this has enabled a higher sugar colour target to be achieved. This in turn has reduced the volume of wash water usage and increased the overall crystal content discharged per cycle from the white centrifuges. This has resulted in a significant financial benefit for the factory over a more traditional approach to managing sugar colour, by taking routine hourly sugar samples with the associated laboratory analysis.

The system is also able to detect non-conforming product that is occasionally produced through issues with centrifuge operations (e.g. block spray nozzles) and divert the resultant "out of specification" product back to the process, rather than forward to the sugar storage silos.

References

1 Sugar Trading Manual, 2000, Woodhead Publishing Limited, Chapter 1, Page 12 (edited by Jonathan Kingsman and Corina Gafner)

2 Maillard, L.C., 1912. Réaction générale des acides aminés sur les sucres. Journal de Physiologie, 14, p.813.

3 International Sugar Journal, 2004, VOL 106, N0. 1269. Colour measurement directly on production line: A quick payback. C. Bacon, B. Black and T. Curenti.