A REFINER'S EXPERIENCE OF ON-LINE COLOUR MEASUREMENT

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Abstract

The colour of washed white sugar is a key indicator of sugar quality. To ensure its quality, sugar is very often over-washed in the centrifugals, with a resultant increase in refining costs. In 1999, a Neltec ColourQ automatic colorimeter was installed to provide on-line colour measurements of wet sugar after the centrifugals. Until 2007, this system was used for indication purposes only, with the operators manually changing the water spraying time. A reduction in colour variability, and an average colour closer to the desired value was achieved. In 2007, an automatic water spraying system was installed; there was a further decrease in variability, and the average colour was closer to the target value.

A spreadsheet model of the refinery was used to evaluate the benefits of the system. Model parameters were determined experimentally, and savings in water and steam were calculated for the whole refining process.

Installation

The Neltec ColourQ colorimeter was installed over the wet sugar 'grasshopper' conveyor in 1999 (figure 1). For easy visualisation and operation, a computer monitor was placed in front of the centrifugals (figure 2).

Figure 1. Measuring unit installed over the wet sugar 'grasshopper' conveyor.

Figure 2. Display monitor and automatic water spraying control unit.

Calibration using wet sugar samples was carried out during commissioning, following the same procedure as used with other installations [1]. A weekly instrument adjustment with a calibration tile was carried out manually, every Monday when the refinery was started-up. In 2004, an auto-adjustment unit was added to the system (figure 3). This unit automatically makes an hourly adjustment to compensate for dust accumulation on the lenses and ambient temperature variations.

Figure 3. ColourQ measuring position (left) and adjustment position (right).

In 2007, the automatic water spraying controller module was added to the existing system. The cabinet containing the PLC and operator panel was placed beneath the monitor (figure 2).

Results

For decades, it was standard practice to take a wet sugar sample from the second discharge of a centrifugal, for every vacuum pan batch (30 to 36 per day). The sample was then sent to the laboratory and analysed immediately. The first discharge was washed for a long time to ensure the desired quality was achieved. Then the operator reduced the spraying time based on his own visual assessment and collected the sample from the second discharge. Approximately 10 minutes later, the operator was informed of the colour of the sample and the spraying time was corrected if necessary. If the colour was outside established limits, a second sugar sample was collected and analysed to provide information for a further spray time correction. In practice, batches with either too high or too low a colour were inevitable because, by the time colour was known, the crystalliser was nearly empty. Figure 4 shows one month of laboratory-measured wet sugar colour with manual control of the spraying water. The average colour was almost 20 IU below the limit. Colour is determined using the ICUMSA Method GS2/3-9 (1994).

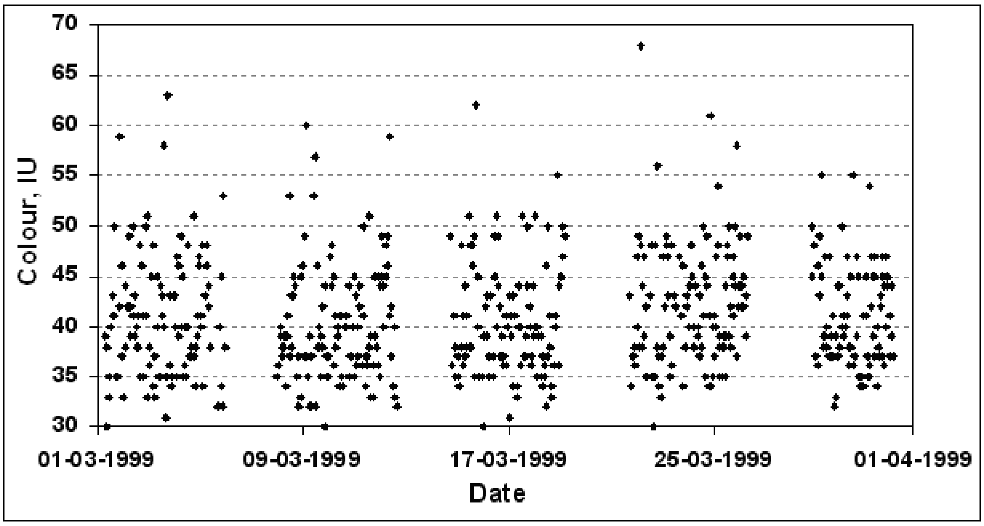

Figure 4. Colour using manual control of spraying water, before ColourQ installation. Colour limit: 60 IU; average colour: 40.7 IU; standard deviation: 6.1 IU (568 lab analyses)

After commissioning, the ColourQ was used to assist operators set the spraying time. Colour limits for manual operation were set to 35 IU (lower) and 50 IU (upper). The lower operating limit was increased by 10 IU, from 35 IU to 45 IU with the upper limit increased by 5 IU, from 50 IU to 55 IU. The average colour increased by 8.3 IU (from 40.7 IU to 49.0 IU) and the standard deviation decreased by 2.4 IU.

After some months of stable operation, the lower limit was increased by 5 IU. The same upper limit was maintained as before (55 IU) thus providing a safety margin of 5 IU. Figure 5 shows the colour measured, from the weeks before the lower limit change to those after. The average colour increased by 2.7 IU (from 49.0 IU to 51.7 IU) and the standard deviation decreased by 1.2 IU.

These settings were mantained in the following months, giving the operators and plant managers time to familiarise themselves with the instrument and gain confidence using it. In February 2002, the limits were increased by 3 IU resulting in the average colour increasing by 3.1 IU, from 51.9 IU to 55.0 IU (figure 6).

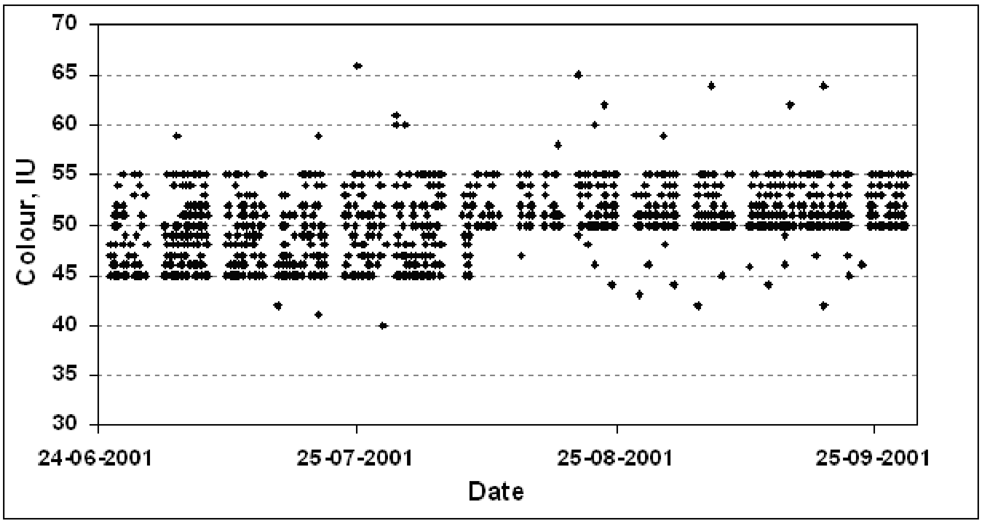

Figure 5. Manual control of spraying water with assistance from the ColourQ.
Operating limit change: August 8, 2001; colour limit: 60 IU
Before – Average colour: 49.0 IU; standard deviation: 3.7 IU (673 lab analyses)
After – Average colour: 51.7 IU; standard deviation: 2.5 IU (680 lab analyses)

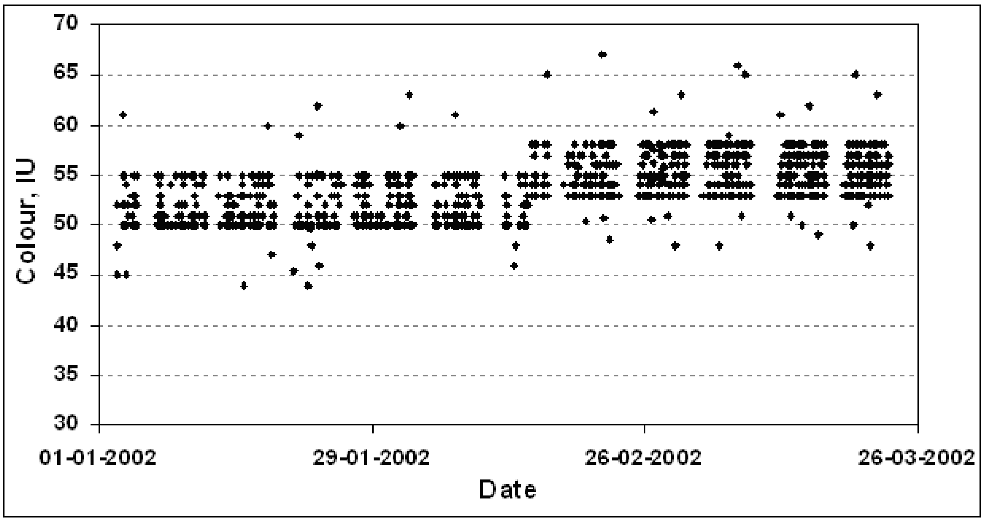

Figure 6. Wet sugar colour limits increase (February 13, 2002); colour limit: 60 IU
Before – Average colour: 51.9 IU; standard deviation: 2.4 IU (514 lab analyses)
After – Average colour: 55.0 IU; standard deviation: 2.3 IU (691 lab analyses)

By 2003, market conditions began to change: some customers were being supplied with 60 IU sugar, others where demanding 45 IU sugar and a 52 IU sugar was produced to obtain a finer sugar by sieving.

In 2004, the auto-adjustment unit was added to the system. In July 2007, the automatic sugar wash module was installed to increase consistency. Figure 7 shows the production schedule in effect by mid-2007.

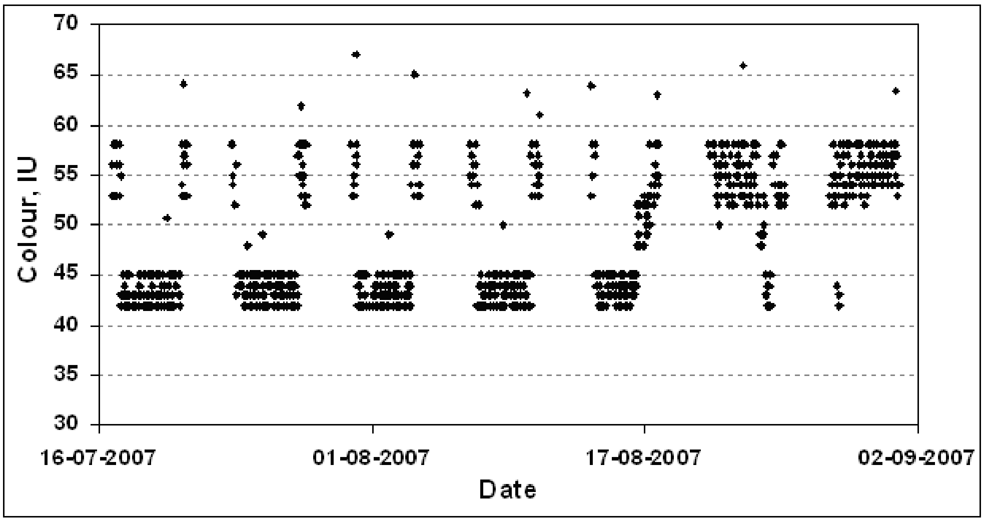

Figure 7. Production of sugar with colour limits of 45 IU, 52 IU and 60 IU.

During this time, the system proved to be very flexible and reliable. From 2008, producing three different sugars was no longer viable and, subsequently, all the sugar produced has been with a colour of 45 IU (figure 8).

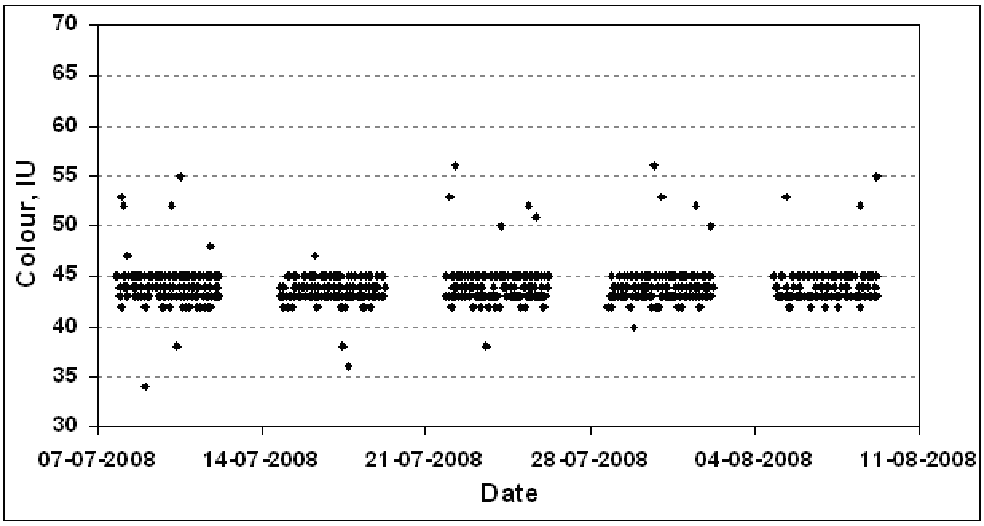

Figure 8. Production of 45 IU sugar using automatic water spraying control.
Average colour: 44.0 IU; standard deviation: 1.7 IU (780 lab analyses)

Operating limits where later increased from between 42 IU and 45 IU to between 44 IU and 46 IU. This increase took into account an expected decrease in colour during sieving, due to the removal of the finer crystals that have a higher colour (figure 9).

In January 2011, the decision was taken to reduce the number of laboratory colour analyses to 6 per day: at the beginning and in the middle of each shift. This represents a saving of five hours of laboratory work per day.

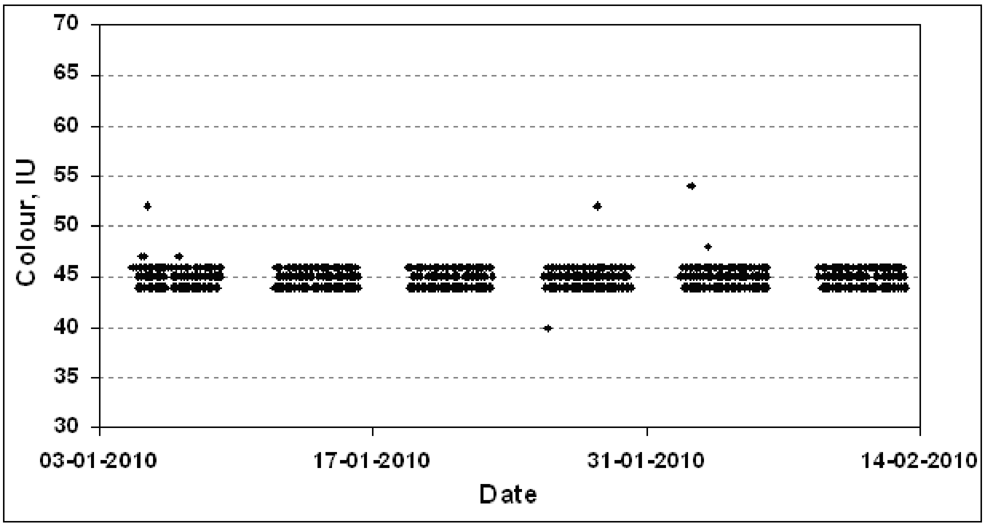

Figure 9. Production of 45 IU sugar with automatic water spraying control. Average colour: 45.0 IU; standard deviation: 1.0 IU (911 lab analyses)

Modelling

The calculations of the savings achieved from the reduction of wash water [2, 3] are restricted to the balance around centrifugals and vacuum pans. Whilst representing the largest percentage of saving of water and steam, a full assessment needs to include the entire refining process. A spreadsheet model of the refinery was used to evaluate the benefits of reduced spraying time. The model includes material, energy and colour balances. The average values of one month's worth of experimental data were used to determine model parameters such as percentage decolourisation, centrifugal yields and water and steam consumption as a function of process flow. Savings resulting from the changes to the average colour were then estimated by comparing steam and water consumption before and after a change to the operating limits for colour.

To assess the effect of a reduction of wash time, the relationship 'sugar colour' *vs*. 'wash time' has to be determined experimentally. An equation with the general form $C=(a+b\cdot t)/(1+c\cdot t)$ was used, where C is sugar colour, t is wash time and a, b, c are constants calculated using data fitting.

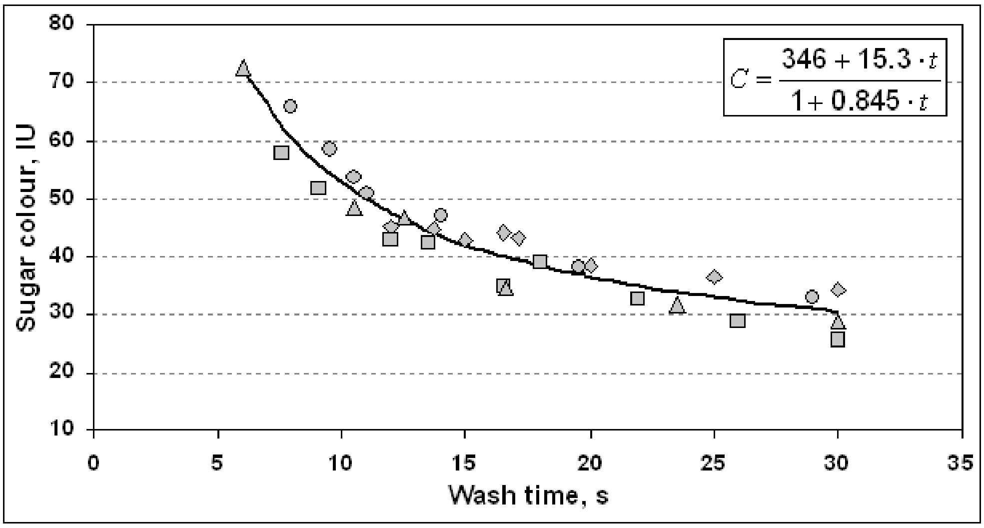

Figure 10. Experimental 'sugar colour' *vs*. 'wash time'.

Samples from four consecutive boilings in three vacuum pans were used to evaluate the constants (figure 10). Each point on the graph represents the average colour of a discharge given as measured by the ColourQ instrument. Although the data were obtained in 2011, the correlation has been used to model past operation because the refining process (affination, carbonatation, ion-exchange, back-boiling) has not changed.

Savings Calculation

The effect of reducing the volume of spray water was calculated as follows:

i) Calculate the wash time from the colour, using the fitted equation solved for *t*, for cases before and after the changes in average sugar colour;
ii) Evaluate how much spray water has been saved per cycle, using the spray-bar ejector's flow curve;
iii) Calculate the amount of excess sucrose dissolved per cycle, assuming that the water is saturated at the massecuite temperature [4];
iv) Calculate the amount of centrifuged sugar for a given centrifugal yield, the amount of centrifuged sugar without excess dissolution and the new centrifugal yield;
v) Run the spreadsheet model with the data from before the colour change and calculate the total water and steam consumption for the whole process;
vi) Determine the number of cycles from massecuite flow estimated by the spreadsheet model and calculate the amount of water saved in centrifugation;
vii) Run the spreadsheet model using the data after the colour change, using the new centrifugal yield with the reduced water in centrifugation and estimate total water and steam consumption for the whole process.

This procedure was applied when colour limits were changed in 1999 (from 40.7 IU to 49.0 IU), 2001 (49.0 to 51.7 IU), 2002 (51.9 to 55.0 IU), and 2010 (44.0 to 45.0 IU). Water and steam costs for each year were used to calculate total savings. Table 1 shows an example of a savings calculation.

Table 1. Example of a savings calculation (base: 10 000 ton of raw sugar).

Colour =	40.7	49	IU	
Wash time =	**16.0**	**11.4**	s	colour' vs. 'wash time' equation: t=(346-C)/(0.845 C-15.3)
Δt =	**4.6**	s/cycle		=16.0-11.4
Q ejectors =	**72.5**	L/min		from ejectors flow curve
ΔVolume =	**5.6**	L/cycle		=4.6*72.5/60
T =	75	°C		
Brix saturation =	**77.6**	°Bx		$=64.397+7.25x10\text{-}2\cdot T+2.0569x10\text{-}3\cdot T^2\text{-}9.035x10\text{-}6\cdot T^3$ (eq. Charles)
Sucrose dissolved =	**19.3**	kg/cycle		=5.6*77.6/(100-77.6)
Centrifugal capacity =	1250	kg/cycle		
Filling =	75	%		
Massecuite =	**937.5**	kg/cycle		=1250*75/100
Centrifugal yield =	50.0	%		
Centrifuged sugar =	**468.8**	kg/cycle		=937.5*50.0/100
Without dissolution =	**488.1**	kg/cycle		=468.8+19.3
New centrifugal yield =	**52.1**	%		=488.1/937.5*100
Massecuite =	20371	ton		from simulation @ 40.7 IU
Number of cycles =	**21729**	cycles		=20371/937.5
Water reduction =	**121.2**	ton		=5.6*21729/1000

From simulation spreadsheets:

	Water	Steam	
Before	8305	9074	from simulation @ 40.7 IU
After	8134	8929	from simulation @ 49.0 IU
Saving, ton	171	145	
Saving, €	371	1295	
Total saving, €	**1666**	€/10 000 ton raw sugar	

From the installation of the ColourQ until 2003, the sugar colour limit was set to 60 IU. For this period, the benefits of the system can be estimated by calculating the steam and water savings, working from each year's colour average, compared to the operator controlled colour average. The total savings for this period were approximately 124 000 €.

Table 2. Steam and water savings from 2000 to 2002 (colour limit 60 IU).

Year	Steam savings (ton/10 000 ton RS)	Water savings (ton/10 000 ton RS)
2000	145	171
2001	163	177
2002	217	215

From 2003 to 2008, sugar with colour limits of 60 IU and 45 IU was produced in different proportions. After 2008, all sugar was produced with a colour limit of 45 IU. When producing 45 IU sugar, we have conservatively assumed that the operator controlled colour would be 5 IU below the limit. Table 3 shows the estimated steam and water savings.

Table 3. Steam and water savings for 60 IU and 45 IU sugar (2003 to 2011).

Colour (IU)	Steam savings (ton/10 000 ton RS)	Water savings (ton/10 000 ton RS)
45	121	117
60	223	221

Average yearly costs of steam and water were used to estimate the total savings. The estimated savings for this period are 368 000 €. Since 2009, all sugar has been produced with a colour limit of 45 IU; the estimated savings from 2009 to 2011 are 194 000 €. Across the whole working period, the total estimated savings are 641 000 €. The average yearly raw sugar melting is 136 000 ton (640 ton/day, 5 days/week).

Costs

System costs are made up of acquisition costs and maintenance costs. Acquisition costs are the costs of the initial purchase of the ColourQ, auto-adjustment unit, automatic wash units and an extra operator display: these costs totalled 63 985 €. Maintenance costs comprise replacement of damaged equipment and periodic lamp replacement: these totalled 4 790 €.

Conclusions

In over 12 years of operation, the on-line ColourQ instrument has proved to be an invaluable tool in reducing refining costs. It is reliable, maintenance costs are low and the instrument itself requires little attention. Payback time is quick, even for a refinery with a small capacity – the total expense of the equipment is a small percentage of the savings achieved. Apart from allowing a fast optimisation of centrifugals, the ColourQ was helpful detecting problems with spray-bar ejectors, basket screen blockage and problems in crystallisation.

Modelling the refining process showed that savings in the pans and centrifugals represent approximately 75% of total savings; the other 25% occur in recovery (20%) and in the remaining process (5%). An increase of 1 IU in average sugar colour has the following benefits: 0.5% decrease in massecuite volume to the centrifugals; 0.4% less sucrose in the molasses; a 3% decrease in the amount of recycled sugar (from recovery). This also means there is a potential to increase refining capacity, depending on the refinery bottleneck.

References

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