FINAL REPORT 2020/2022

IMPROVING PAN STAGE PERFORMANCE BY ON-LINE MONITORING OF C SEED GRAININGS USING THE ITECA CRYSTOBSERVER

FINAL REPORT PREPARED BY	Kent Selby Gabriel Fraga Ross Broadfoot
CHIEF INVESTIGATOR(S)	Kent Selby (Condong Mill) Ashely Curran (Condong Mill) Aaron Baker (Condong Mill) Ross Broadfoot (QUT)
RESEARCH ORGANISATION(S)	Sunshine Sugar, QUT
CO-FUNDER	Sunshine Sugar, QUT
DATE	October 21, 2022
RESEARCH MISSION(S)	Mission #1

Please cite as: Selby, K., Fraga, G., Broadfoot, R., (2022) Improving pan stage performance by on-line monitoring of C seed grainings using the ITECA Crystobserver: Final Report 2020/202. Sugar Research Australia Limited, Brisbane

ABSTRACT

A microscope system called Crystobserver (supplied by ITECA, France) was installed on the C seed pan at Condong Mill to monitor the crystal development in real time. The system provides a high-quality image and measures important parameters such as average crystal size and the number of crystals in the image. Analysis of data collected over two seasons confirms that the system is reliable in obtaining images with sufficient clarity to assist the operators in remotely monitoring the crystal development from shortly after slurry addition. The reliability of the measurements is satisfactory once the crystals are larger than 30 µm through to near the end of the C seed, when the crystal density in the screen is high. The pan operators have found the Crystobserver to be very beneficial and has allowed them to take corrective actions such as changing the amount of slurry addition or the purity of the graining blend more quickly. The software in the system stores historical data from several strikes, including images and key parameters which can be readily accessed.

The Crystobserver would also be ideal for monitoring the magma wash operation. In addition, it works as an excellent resource for storing historical data.

EXECUTIVE SUMMARY

A microscope system called Crystobserver (supplied by ITECA, France) was installed on the C seed pan at Condong Mill to monitor the crystal development in real time. The system provides a high-quality image and measures important parameters such as average crystal size and number of crystals in the image. Importantly, the Crystobserver requires little to no maintenance and the quality of its images is excellent.

Analysis of data was undertaken to understand the reliability of the system over long periods of operation, demonstrating that the quality and brightness of the images is consistent. In addition, the software can store historical data for several crushing seasons and has several features that were proven useful for analysing trends in parameters. The evaluation of several runs has shown that the crystal size data has very consistent profiles with time, from time zero till it reaches 150 µm. During the early stages, where the size is smaller than 40 µm, a rapid crystal growth was observed. This is likely to be a result of inaccuracies with the vision system because of the background sludge in the graining blend. Similarly, at the end of the strike (> 120 min), often the average crystal size is overestimated, and this is attributed to the higher crystal density at the end of the cycle leading to inaccuracies in the measurements by the software.

The main advantage of the Crystobserver is to the pan stage operator who, based on the experience at Condong Mill, may use this information for: (i) minimising the need to proof the pan and check in the pan floor microscope, (ii) early monitoring of the success or otherwise of the formation of the crystals from the slurry particles (iii) general troubleshooting, (iv) observing anomalies, e.g., elongation or conglomerates, (v) deciding whether to change the brix (conductivity) set point for graining, (vi) making decisions on the graining procedure by reviewing the images and key parameters from the previous shifts (vii) detecting fine grain early if it forms or (viii) observing the crystal growth rate during run-up and deciding if a change in conductivity set point is required.

Through observations of grain formation, growth rates and the extent of conglomeration the Crystobserver may guide a decision on whether to reduce the blend purity e.g., from 70 to 68 units. In this scenario, a reduction in final molasses purity would be expected and more sugar product would be recovered. The financial return is strongly dependent on the throughput rate of the factory, but for a factory processing 1.5 M tonne cane per annum the NPV is AUD 86,000, IRR 36% and the payback period is three seasons.

The Crystobserver would also be ideal for monitoring the magma wash operation.

CONTENTS

ABSTRACT 1
EXECUTIVE SUMMARY 2
TABLE OF TABLES 4
TABLE OF FIGURES 4
1 BACKGROUND 5
1.1 General comments on the operation of C grainings in Australian factories 5
1.2 Purpose of the investigation 5
2 PROJECT OBJECTIVES 5
3 OUTPUTS, OUTCOMES AND IMPLICATIONS 5
3.1 Outputs 5
3.2 Outcomes and Implications 6
4 INDUSTRY COMMUNICATION AND ENGAGEMENT 7
4.1 Industry engagement during course of project 7
4.2 Industry communication messages 7
5 METHODOLOGY 7
5.1 Overview of the work program 7
5.2 Graining procedure at Condong Mill 8
5.3 Installation and commissioning of the Crystobserver 8
5.3.1 Description of the Crystobserver components 8
5.3.2 Visit by ITECA technician 12
5.3.3 Images, crystal population parameters and alarms 12
6 RESULTS AND DISCUSSION 15
6.1 General comments 15
6.2 Use of the Crystobserver by the pan stage operators 15
6.3 Analysis of Crystobserver data 16
6.3.1 Successive runs with the Crystobserver 16
6.3.2 Low and high purity seeding 19
6.3.3 Comparison of data obtained by Crystobserver and digital microscope 20
6.3.4 Crystal growth rates 23
6.4 Use of the Crystobserver for troubleshooting 24
6.4.1 Presence of conglomeration 26
6.5 Benefits of using the Crystobserver in Australian sugar factories 28
6.6 Maintenance of the Crystobserver 29
7 Applications of the Crystobserver in sugar factories 29
7.1 Recommendations for installation and commissioning in Australian factories 29
7.2 Use of the Crystobserver by factories 29
7.3 Shortcomings 30
7.4 Potential additional uses of the Crystobserver 30
7.5 Alternatives to the Crystobserver 30
7.5.1 Pixact Crystallization Monitoring (PCM) 30
7.5.2 Canty SugarScope 31
7.5.3 Summary 32
8 CONCLUSIONS 32

9 RECOMMENDATIONS FOR FURTHER RD&A ... 33
10 PUBLICATIONS ... 33
11 ACKNOWLEDGEMENTS ... 33
12 REFERENCES ... 33
13 APPENDIX ... 34
13.1 Additional features of the system ... 34
13.2 Appendix 1 METADATA DISCLOSURE ... 36
14 SRA RESEARCH MISSIONS MANAGER'S RECOMMENDATION ... 37
SRA Research Missions Manager's comments: ... 37
Recommendation: ... 37

TABLE OF TABLES

Table 1. Successive images of 2 cycles of reasonable quality ... 13
Table 2. Data at the end of a strike extracted from Crystobserver for the period between 11-13/08/22 ... 17
Table 3. Data at several periods of two strike examples (low and high purity feed) extracted from the Crystobserver. ... 20
Table 4. Comparison between data from the Crystobserver and samples collected and measured in a digital microscope (12/09/22) – Part 1. ... 22
Table 5. Comparison between data from the Crystobserver and samples collected and measured in a digital microscope (12/09/22) – Part 2. ... 23
Table 6. Growth rate calculated for the 8 strikes evaluated from 11-13/08/22. ... 24
Table 7. Crystobserver images of two cycles: typical (left) and poor (right). ... 25
Table 8. Crystobserver images containing conglomeration: at 30 minutes after slurry addition (left) and end of cycle (right) ... 27
Table 9. Assumptions for the financial analysis ... 28
Table 10. NPV, IRR and payback period estimated for different cane crop sizes ... 29
Table 11. Metadata disclosure 1 ... 36
Table 12. Metadata disclosure 2 ... 36

TABLE OF FIGURES

Figure 1. Schematic of the Crystobserver image capturing system. ... 9
Figure 2. Drawing of the components in the interior of the Crystobserver case. ... 9
Figure 3. Crystobserver computer installed in the control room in Condong Mill. ... 10
Figure 4. Crystobserver installed on the C seed pan at Condong Mill ... 10
Figure 5. Closer image of the Crystobserver showing the air and hot water supplies ... 11
Figure 6. Screenshot of the Crystobserver software installed in a dedicated computer in the control room. ... 12
Figure 7. Screenshot of historical data of 3 successive strikes from 07/09/22. ... 14
Figure 8. Plots of MA, CV, and crystal number for the 8 strikes analysed. *Upper and lower limits for alarms in red. Note: 180 min means the discharge point, which varies according to the strike.* ... 18
Figure 9. Plots of MA and crystal number for the low and high purity strikes analysed. *Note: 180 min means the discharge point, which varies according to the strike.* ... 19
Figure 10. Photograph of the slide (left) and the digital microscope (right). ... 21
Figure 11. Illustration of the back-lit setup and imaging principle (Hannu et al. 2019). ... 30
Figure 12. Installation on the boiling pan sight glass (left) and example image of the crystal suspension (Hannu et al. 2019). ... 31
Figure 13. Drawing of the SugarScope insertion (JM Canty 2022). ... 31
Figure 14. Example of crystal images from the SugarScope at various time points from initial seeding (JM Canty 2022). ... 32

1 BACKGROUND

1.1 General comments on the operation of C grainings in Australian factories

Pan stage crystallisation is largely undertaken without direct control of the main process parameters. For example, there is no supersaturation measurement and no crystal sizing on-line system. Indirect measures such as conductivity and ad hoc checking of proof samples under a microscope are currently used. Production of C grainings at specification on a consistent basis with respect to crystal numbers, mean aperture and coefficient of variation is an important first step for pan stage operations as it provides flow on benefits to the C massecuite production, C fugal operations, C sugar magma preparation, A and B massecuite boilings and fugalling. Hence, tighter control of C seed production provides potential benefits in sugar recovery, sugar quality, pan stage throughput, and steam and water consumptions.

1.2 Purpose of the investigation

One of the critical steps on the pan stage is the C seed graining to produce the foundation crystals for the stage, from slurry. This project investigates the use of the ITECA Crystobserver to monitor the crystal development in the C seed pan at Condong Mill. The ITECA Crystobserver is an online HD video pan microscope that allows crystal growth to be directly monitored in real time. As far as is known by the authors this instrument had not been previously tested in a raw sugar cane factory and particularly not in a highly coloured molasses as is present in C seed production. Most applications for the Crystobserver have been in high purity beet boilings and refinery boilings.

This project evaluated the use of the Crystobserver to improve the consistency of C seed crystal production. The instrument provides on-line measurement of crystal numbers, mean aperture and coefficient of variation, and is reported to be capable of measuring crystals as small as 10 microns.

For the investigations on C seed production with the aim to improve consistency of outcomes, the key parameters provided by the Crystobserver for production staff are (1) the delay time from slurry injection until the crystals reach a certain size e.g., 50 microns, (2) the number of crystals in the field of view, and (3) crystal growth rates from say 10 microns to 50 microns. Improved consistency and quality of the C seed will improve the operations and performance of the whole stage.

2 PROJECT OBJECTIVES

The objectives of the project are to:

- Install the Crystobserver in the batch C seed pan at Condong Mill,
- Commission and calibrate the analyser software,
- Integrate software outputs into the factory's DCS including alarm signals for early detection of process deviations,
- Train operators to assess the C graining performance using the analyser outputs,
- Evaluate the benefits to the pan stage and factory performance and undertake a cost/benefit analysis resulting from improved production of C grain,
- Develop recommendations for future applications for C graining and other applications on the pan stage, for example magma preparation plan.

3 OUTPUTS, OUTCOMES AND IMPLICATIONS

3.1 Outputs

The outputs for the project are:

- Demonstrated effectiveness of the Crystobserver to detect small crystals, provide a reliable number count in the field of view and provide reliable measurements of mean aperture and coefficient of variation of the crystal population in the C seed production step,
- Demonstrated ability for production staff (pan stage operators, shift supervisors and managers) to use the data from the Crystobserver in conjunction with other process data to troubleshoot deviations from targeted production of C grainings. Key information provided by the Crystobserver and used by the production staff has been:
    - Identification of any rogue crystals in the blend of A and B molasses
    - Time from slurry addition to when the image first shows the presence of small crystals and provides a qualitative indication of the number of crystals being established. The operator quickly assesses whether the graining is likely to be successful

  - Number density in the image at certain times through the crystal establishment phase e.g., at 15 and 30 minutes after slurry addition
  - The extent of conglomeration
  - The consistency of MA and crystal number at pan cut out to the C massecuite pan.

    Importantly the pan operators have found the system to be user friendly and provide reliable assessments of the quality of grainings. Consequently, they have used the information to make corrections, if required, to the subsequent graining and so achieve tighter pan stage operations.
- Benefits in sugar recovery, shipment sugar quality (e.g., consistency in mean aperture), throughput, steam consumption and water usage for the pan stage are expected to result from tighter control of the C seed grainings. However, it has not been possible to measure these directly from factory records owing to the impacts of other factors such as variable composition of the cane supply. Nevertheless, qualitatively, several benefits are clearly obtained through the pan operators using the results to improve consistency in the C seed and troubleshoot deviations from ideal operation,
- Cost/benefit analysis of using the Crystobserver for monitoring the C seed graining cycle with the aim to use a blend of slightly lower purity for graining to reduce conglomeration, reduce the C massecuite purity and increase sugar production by reducing the sucrose loss in final molasses,
- Recommendations for using the system at other factories,
- Assessment of other applications on the pan stage to suit the Crystobserver.

Pan stage operators, Production Managers and Instrument Engineers will use the supplied information to implement the Crystobserver at their factories.

3.2 Outcomes and Implications

The main outcomes for Australian sugar mills from use of the ITECA Crystobserver on the C seed pan are to provide reliable real time information to the pan stage operator on the development of the graining and to allow adjustments to the subsequent graining to achieve a more consistent C seed at specification with respect to MA and crystal number. By consistently achieving a better quality of C seed massecuite improved operations of the pan and fugal stations are expected. No attempt has been made to analyse factory production data records as the variable cane conditions (large variations in cane purity associated with flooded paddocks, etc.) would make it very difficult to statistically quantify the benefits. Nevertheless, benefits are expected in terms of sugar recovery, sugar quality, pan stage throughput, and steam and water consumptions.

A financial analysis has been conducted to estimate the increase in sugar production that would be obtained if, through data available on the Crystobserver, the purity of the blend used for grain establishment is reduced, thus reducing the purity of the C massecuite and achieving a reduction in the purity of the final molasses.

For a factory processing 1.5 M tonne cane per annum the NPV is AUD 86,000, IRR 36% and the payback period is three seasons. Details of the financial analysis are provided in Section 6.5. As each factory has only one C seed pan for grain establishment, the financial return is strongly dependent on the throughput rate of the factory.

The technology would be applicable for use in all Australian mills for monitoring the C seed graining. New applications for the system would likely be on the magma preparation pan, which would provide further financial benefits in recovery and sugar quality.

The installed cost for the Crystobserver is ~AUD 77,000 (including AUD 10,000 local installation cost) for a single unit, although some savings through shared components (mainly the control box which is capable of servicing two camera systems and the PC for up to six systems) exist when a factory installs multiple systems e.g., one on the C seed graining and one on the magma preparation pan. The installation of a second system on the same order and commissioning adds an extra AUD 24,000.

The outputs of this project will be utilised by Pan Stage Operators, Production Supervisors and Production Managers in all Australian factories.

As demonstrated through the installation at Condong Mill the mill instrumentation staff are able to undertake the installation, with remote guidance from ITECA technicians.

4 INDUSTRY COMMUNICATION AND ENGAGEMENT

4.1 Industry engagement during course of project

The concept from this project was presented to mill staff at the Regional Research Seminar series conducted by QUT in March 2022. The final results will be presented in the seminar series in March 2023. The results will be published as a paper to the ASSCT 2023.

The information available for adoption by the Australian sugar industry is listed in the Outputs.

4.2 Industry communication messages

The Crystobserver (supplied by ITECA, France) has provided real time consistent information (image and data) to the pan stage operator. The system provides a high-quality image and measures important parameters such as average crystal size and number of crystals in the pan. Importantly, the Crystobserver requires little to no maintenance.

The reliability of the measurements is satisfactory for most scenarios, except for the beginning of the strike, where the crystals are smaller than 30 µm, and the end, where the crystal density in the image is overly high. Nevertheless, the Crystobserver has shown worthwhile benefits to the pan stage operators, who need to proof the pan much less and can make decisions for corrective actions more quickly. This system may also provide enough information to assist the production management in long-term decisions such as modifying the purity of the blend used for C seeding, which will offer additional income to the plant due to higher sucrose recovery.

The main advantage of the Crystobserver is to the pan stage operator who, based on the experience at Condong Mill, may use this information for: (i) minimising the need to proof the pan and check in the pan floor microscope, (ii) early monitoring of the success or otherwise of the formation of the crystals from the slurry particles (iii) general troubleshooting, (iv) observing anomalies, e.g., elongation or conglomerates, (v) deciding whether to change the brix (conductivity) set point for graining, (vi) making decisions on the graining procedure by reviewing the images and key parameters from the previous shifts (vii) detecting fine grain early if it forms or (viii) observing the crystal growth rate during run-up and deciding if a change in conductivity set point is required.

Through observations of grain formation, growth rates and the extent of conglomeration the Crystobserver may guide a decision on whether to reduce the blend purity e.g from 70 to 68 units. In this scenario, a reduction in final molasses purity would be expected and more sugar product would be recovered. The financial return is strongly dependent on the throughput rate of the factory, but for a factory processing 1.5 M tonne cane per annum the NPV is AUD 86,000, IRR 36% and the payback period is three seasons.

5 METHODOLOGY

5.1 Overview of the work program

The main steps in the work program were:

- Carry out site modifications to allow for the installation of the Crystobserver, control station and provide the required services (power, air, flushing water, communications) on the C seed graining pan at Condong Mill,

- Undertake commissioning and calibration of the instrument by Condong staff and ITECA. Provide training of pan stage operators, process supervisors and QUT project staff provided by ITECA in the operation of the instrument and associated software and how to interpret and use the data in pan stage management.

- Integrate software outputs with the factory’s DCS system and determination of the Alarm and Event triggers that will allow for improved monitoring of massecuite growth conditions and massecuite quality.

- Use of the Crystobserver by the pan stage operators and assess its benefit in monitoring successive grainings and troubleshooting. QUT project staff correlate the Crystobserver data with independent measurements of MA and number count, assess usage by the pan stage operators and potential for improvements in pan stage operations.

- Evaluate the cost/benefit of using the Crystobserver for monitoring the C seed graining. Also assess the suitability of using the Crystobserver in other pans including the C sugar magma preparation pan and high-grade strike pans.

5.2 Graining procedure at Condong Mill

The C seed at Condong Mill is produced in pan 5 which is a straight sided fixed calandria pan of 30 t massecuite capacity. The pan is unstirred and has no functional jigger system. The operators consider that the pan has relatively poor circulation characteristics. One operator usually bleeds air into the feed system of the pan to try to boost circulation. The graining and C seed production procedures are described below:

1. Boil down 18 t blend of A syrup and B syrup at a target of 70 purity. Vacuum prior to graining is 630 mm Hg. Operator monitors conductivity but uses the string test to decide on when to add slurry.
2. Add 250 to 300 mL of homemade rod mill slurry, wait a few minutes until grain is visible on the Crystobserver or under the pan floor microscope. After adding slurry, the operator hits button on the DCS screen, to initiate time zero for the Crystobserver. When they see grain, they activate the ‘Continue button’ on DCS for auto control through the pan’s sequence.
3. Onto balance water for 5 minutes[1]. Increase vacuum to 650 mm Hg. The steam rate is not altered during the slurry establishment phase.
4. Run up on auto feed with B syrup to 30 t.
5. Cut to C massecuite pan (pan 1).
6. When the C seed is completed, the operator saves a screenshot to a file (recorded to the strike number). The operator also takes a proof sample, checks it under the microscope and records the two linear dimensions of an ‘average’ size crystal. Recorded as say 24/21 (being 240 by 210 µm).

At Condong, each batch of rod mill slurry (dried refined sugar, canola oil and isopropanol), is stored on the pan stage in large containers and as required decanted into smaller bottles. When slurry is required to charge the pan, the slurry is mixed by shaking and the required volume is transferred to a measuring cylinder. The slurry is added via a funnel and pipe (15 NB pipe) above the calandria. The target size for C seed is between 180 and 200 µm.

5.3 Installation and commissioning of the Crystobserver

5.3.1 *Description of the Crystobserver components*

Condong Mill leased the sensor from ITECA (France) in 2020 but commissioning was not possible due to travel restrictions during the COVID-19 pandemic for ITECA engineers into Australia. The installation and commissioning in pan 5 were completed in July 2021 by Condong’s staff, with remote support from ITECA technicians. Importantly, through remote access, ITECA was able to monitor the signal and undertake remote commissioning including calibration and conditioning.

The system is composed of three main elements:

- A stainless-steel housing holding the sensor (4K camera, microscope, light source, motor driven plates, cooling system and sight glass), mounted directly on the pan wall.
- An electrical enclosure with internal PLC, power supply, communication modules, etc.
- A computer, with its image analysis software, located in the control room.

A light source goes through an optical fibre and a stainless-steel tube to illuminate the sample area located between the end of the light tube and the sight glass. The microscope and the high-definition digital camera are directed onto the sight glass. The optical equipment captures very sharp images of the crystals moving in this back lighted area. Figure 1 shows a schematic of the image capturing system and Figure 2 a drawing of the interior of the case where the system is installed.

[1] This procedure was changed in August 2022 to holding on water for 30 minutes in an effort to reduce conglomeration and obtain more consistency.

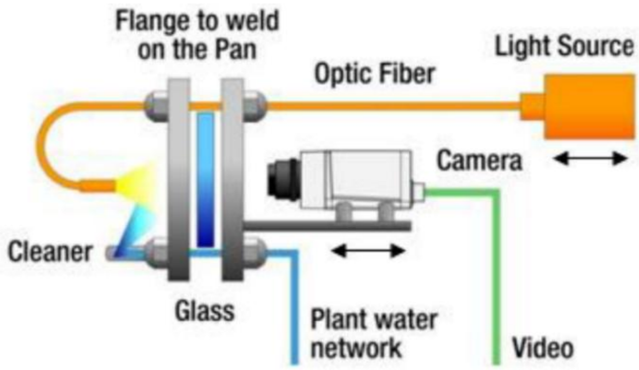


Figure 1. Schematic of the Crystobserver image capturing system.

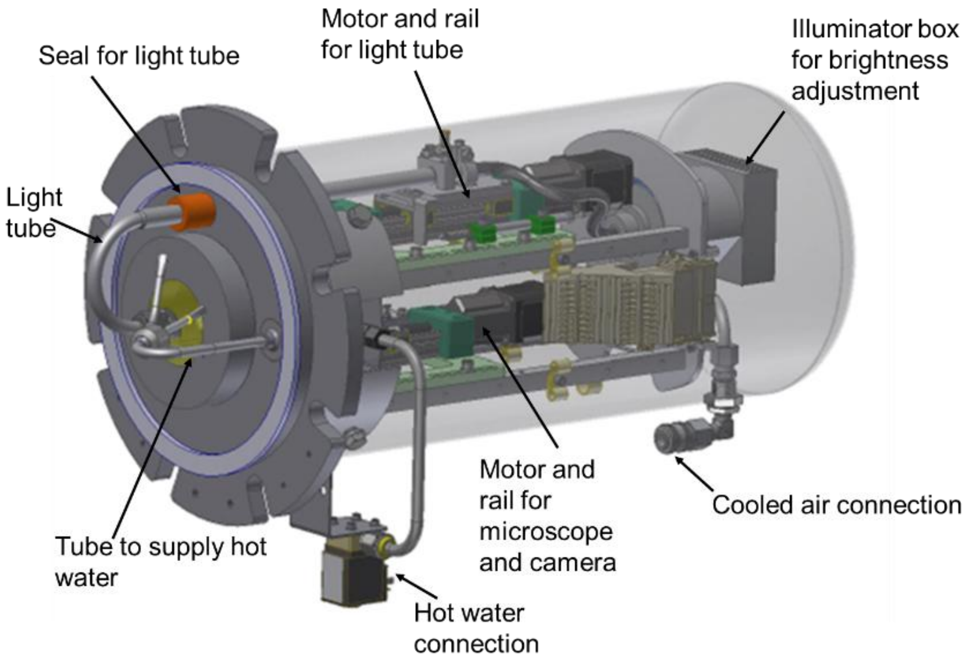


Figure 2. Drawing of the components in the interior of the Crystobserver case.

Images of the crystals are processed on the dedicated PC in the control room, one computer managing up to six sensors. The control box needs to be within 50 metres of the computer. At Condong, the computer is in the control room (Figure 3) and the control box is a few metres from the pan (Figure 4). Two cameras can be linked to one control box. To synchronize the Crystobserver with the pan’s operational sequences, the four following signals are cabled directly to the electrical enclosure: (i) charging of the pan, (ii) seeding (slurry addition), (iii) discharging (cutting out to the C massecuite pan), (iv) cleaning.

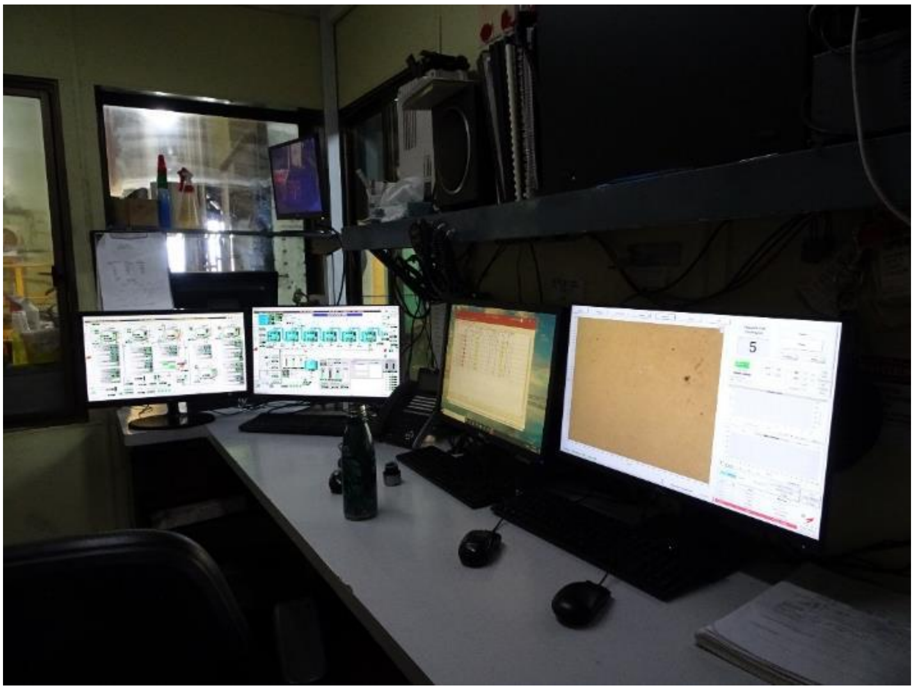


Figure 3. Crystobserver computer installed in the control room in Condong Mill.

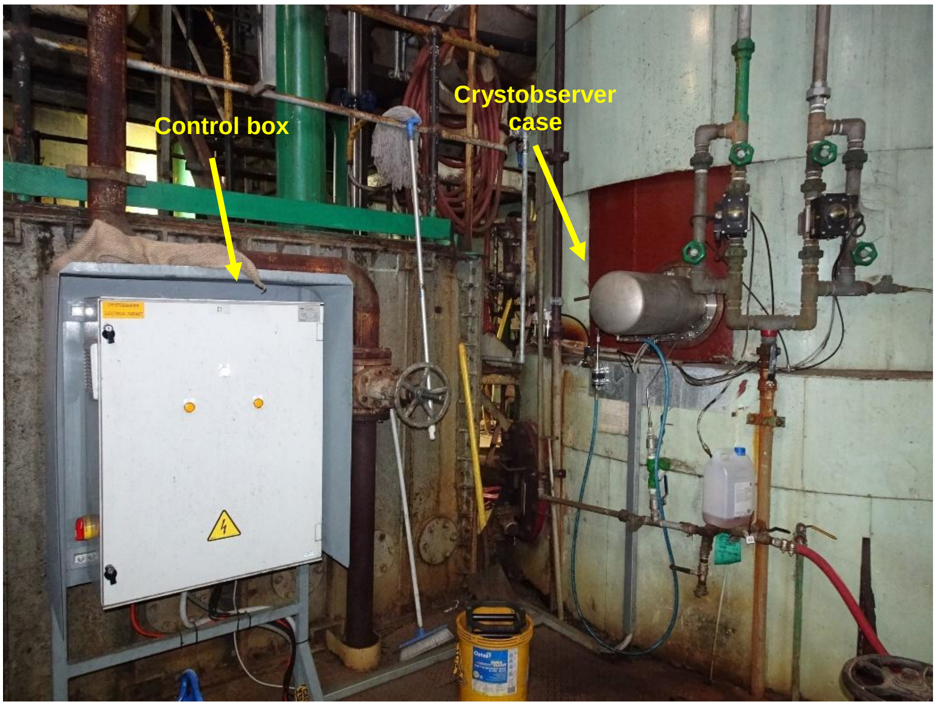


Figure 4. Crystobserver installed on the C seed pan at Condong Mill.

The Crystobserver requires hot water supply (filtered) and instrument air (Figure 5). The air is supplied to a vortex cooler, which supplies cool air to the housing of the microscope and camera. The housing must be kept < 45 °C. The hot water is used to flush the sight glass and clean it according to a pre-determined schedule (discussed below).

The width of the gap between the crystals and the glass is controlled so to avoid glass to glass contact and damage to the crystals. This position is currently fixed for the installation at Condong Mill, but it can be set up with a variable gap according to a predetermined profile to accommodate crystals as they grow larger in size. The aim is to set the gap between the face of the light tube and the sight glass to be small enough that the crystals are largely in a single plane, while avoiding crushing the crystals. The time that the gap is held at the new position is also nominated e.g., 5 mins before the light tube retracts to allow a new sample to flow into the gap. There is still a mechanical gap to avoid glass to glass contact and damage (150 µm). For the installation at Condong Mill the measurement gap is fixed at 100 µm (total gap = 250 µm), the image is 2,700 µm by 2,024 µm and the observed volume in the gap between crystals and glass is estimated at 1.3662 mm^3.

The water flush is directed to two places: (1) onto the sight glass in the gap and (2) onto the light tube just in front of the seal. The current setup is for the flush to be activated every 5 minutes and last for 3 seconds. No measurement is taken during the cleaning step and there is a 60 seconds wait after the clean finishes until measurement is taken. This means that rounded crystals should not be counted, and the MA value is not affected by the wash. A manual clean can also be initiated by the operator via the user interface at any time.

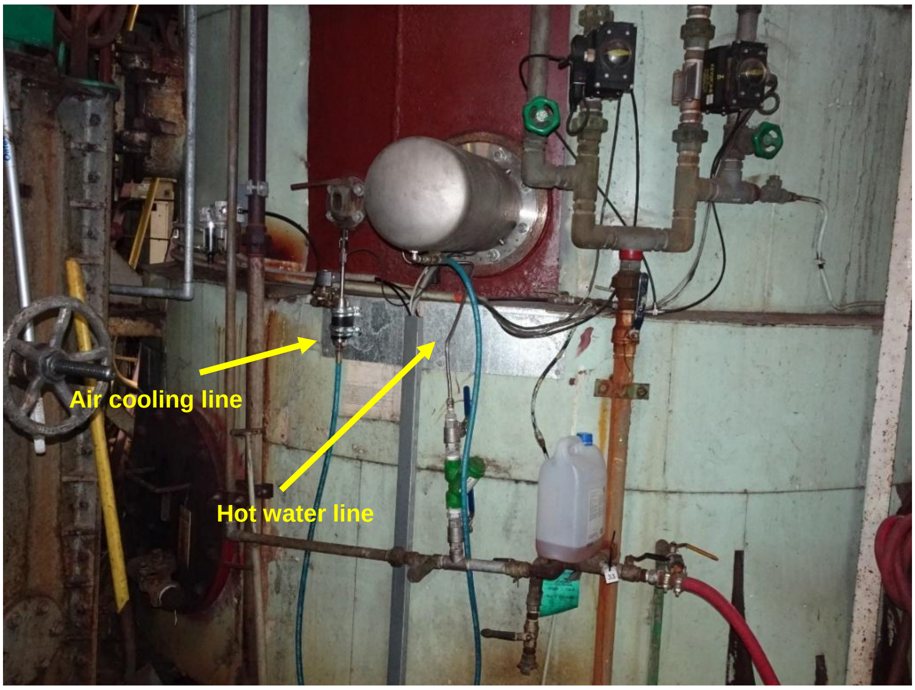


Figure 5. Closer image of the Crystobserver showing the air and hot water supplies

A dedicated computer (supplied by ITECA as part of the package) for the Crystobserver was installed in the control room adjacent to the DCS screens (Figure 3). Figure 6 provides a screenshot of the Crystobserver display. The video of the crystals is presented on the left-hand side and the operation and statistical information such as distribution in size, number of crystals, mean aperture, coefficient of variation or fines percentage, are displayed on the right-hand side. All data, calculation, Excel files, photos and plots can be downloaded into .xls or .pdf formats.

As seen in Figure 6, the quality of the image is excellent. The brightness of the illumination is adjusted automatically so that a consistent illumination of the image is provided.

Using TeamViewer, the real time operation of the sensor was able to be monitored remotely by ITECA, Sunshine Sugar staff and QUT staff and this was invaluable in developing the understanding of the response of the sensor. At Condong a dedicated modem was installed to provide the remote connection to keep separate from the factory and business networks thus eliminating any securing concerns.

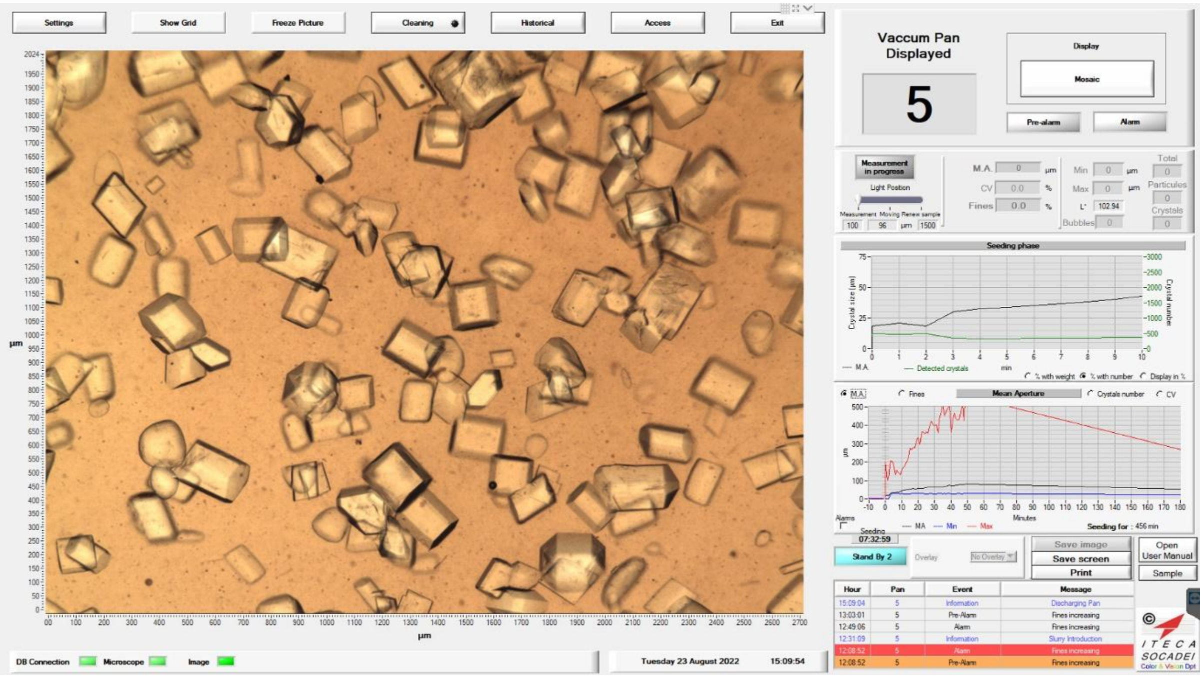


Figure 6. Screenshot of the Crystobserver software installed in a dedicated computer in the control room.

5.3.2 *Visit by ITECA technician*

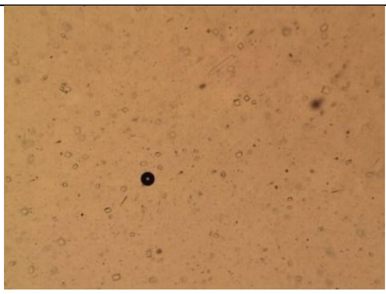
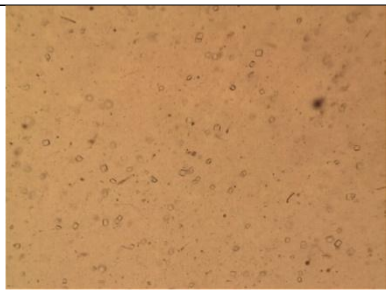
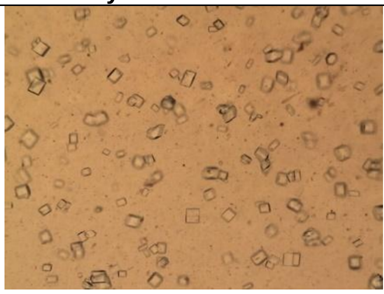
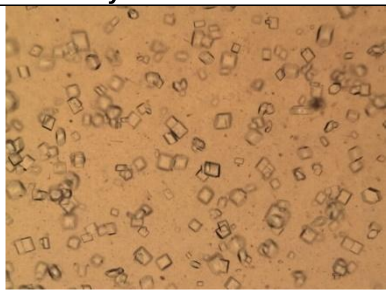
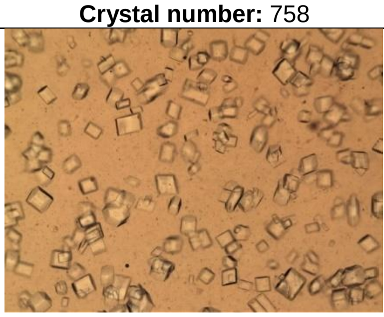
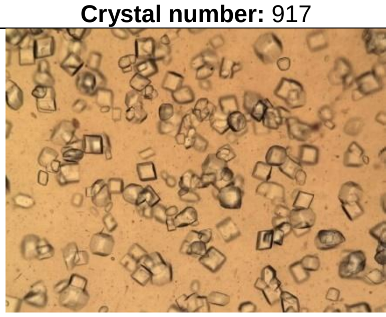
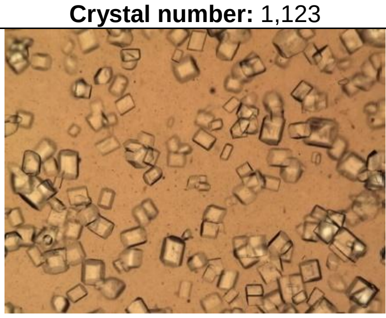
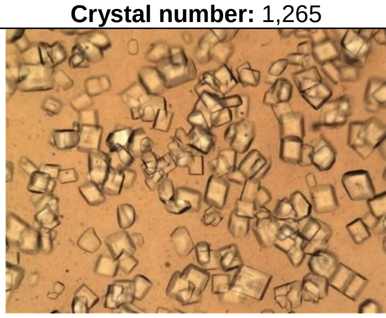
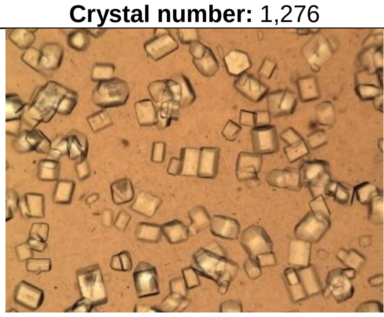
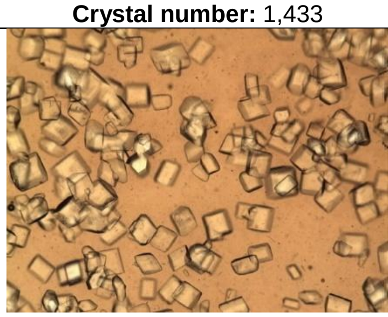
In the period 25 to 28 July 2022 a technician from ITECA attended site and undertook a check on the operation of the Crystobserver, reviewed the stored data and adjusted alarm settings. This provided an excellent opportunity for Sunshine Sugar and QUT staff to learn more about the functions of the software and how to customise to the particular application.

5.3.3 *Images, crystal population parameters and alarms*

5.3.3.1 Examples of images of C seed development

The images in Table 1 show examples of what would be observed in a typical cycle for a typical quality C seed graining at Condong Mill. While variations in the initial and intermediate stages after seeding are observed (30 and 60 min, respectively), the product is at similar conditions of (mean aperture) MA, CV, and crystal number. The consistency of the images with respect to lighting is also a feature of the system, which increases its reliability with the pan operator.

Table 1. Successive images of 2 cycles of reasonable quality

Time after seeding	23/08/22 16:53	23/08/22 20:55
10 min	 **MA:** 40.76 µm **CV:** 27.70% **Crystal number:** 379	 **MA:** 45.95 µm **CV:** 34.42% **Crystal number:** 361
30 min	 **MA:** 65.12 µm **CV:** 35.92% **Crystal number:** 758	 **MA:** 66.79 µm **CV:** 34.50% **Crystal number:** 917
60 min	 **MA:** 93.18 µm **CV:** 37.44% **Crystal number:** 1,123	 **MA:** 90.57 µm **CV:** 33.83% **Crystal number:** 1,265
115 min	 **MA:** 125.14 µm **CV:** 32.99% **Crystal number:** 1,276	 **MA:** 148.86 µm **CV:** 34.61% **Crystal number:** 1,433
Discharge	 **MA:** 209.17 µm **CV:** 36.18% **Crystal number:** 1,178 (139 min)	 **MA:** 246.30 µm **CV:** 37.90% **Crystal number:** 1,364 (137 min)

5.3.3.2 Storage and display of images

A video of each strike is stored in the system, where it can be accessed later for analysis and comparison with other strikes (this is determined by file storage space, i.e., period for video imaging storage could be increased by storing on a dedicated file server). Figure 7 shows a screenshot of this section, where three images of successive strikes are compared with MA at about 100 µm. In this function of the software, one can follow each strike from beginning until discharging (circa 7 seconds intervals), with live information of MA, CV, fines, minimum MA, maximum MA, and crystal number as a function of time. The three selected images do not need to be successive cycles. They can even be selected from previous seasons. Comparisons can be made at any time throughout the strike, from 10 minutes before seeding through to pan discharging by moving the position of the scroll bar. Alternatively, the comparisons can be played as a video with pause and rewind options to view the statistical data at a particular point of interest.

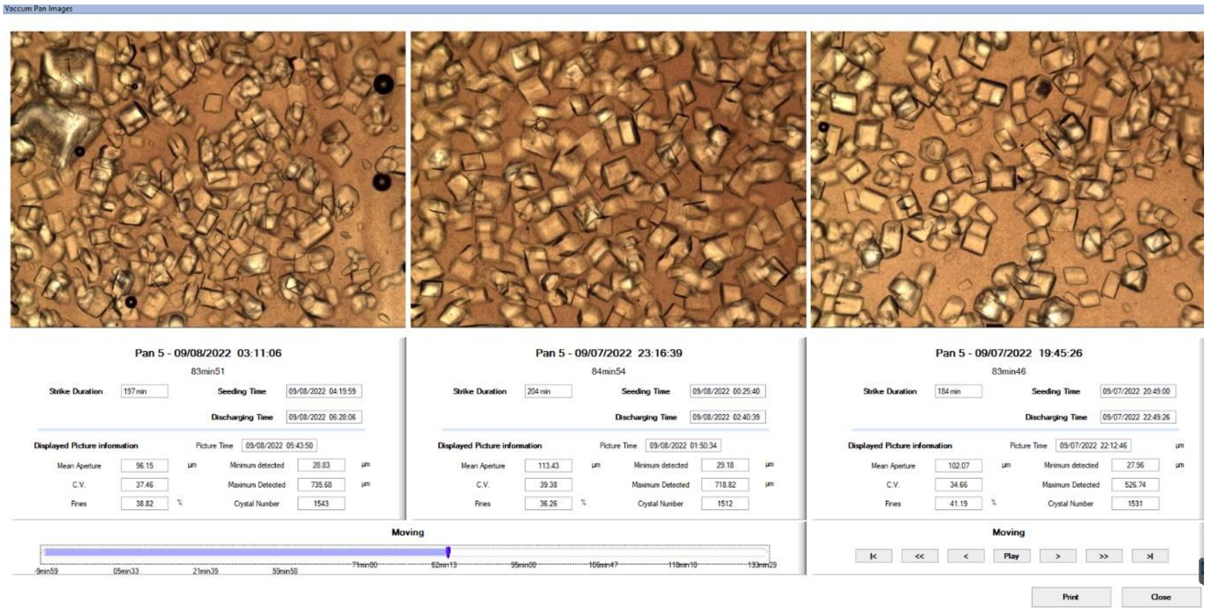


Figure 7. Screenshot of historical data of 3 successive strikes from 07/09/22.

5.3.3.3 Crystal population parameters

The data determined by the Crystobserver are:

- **Mean aperture (MA):** The reported MA data is based on a correlation ITECA developed by sieving 100 to 200 crystals on 10 sieves to give the mass fraction of each sieve size. These data are correlated to the measurements on the image. Sugar dimensions are determined for two cases: (i) crystals that are not touching other crystals (Feret diameter) and (ii) crystals that are touching other crystals. In the second case, the length of the longest straight line is used as a measure of particle size for those particles.
- **Coefficient of variation (CV):** Calculated from the standard deviation and mean aperture values.
- **Crystal number:** The number of data sets taken from the image. It includes whole crystals, when isolated, and the lines on touching crystals. Whole crystals are labelled as “particles” in the screen and individual lines are labelled “crystal”. The sum of the two values is labelled as “total” and is considered as the total crystal number. Only “total” number is stored in the historical data.
- **Bubbles:** Air bubbles counted in the field of view, identified by the software as perfect circles.
- **Fines:** Fines are the number of crystals counted with size < X µm. The threshold size is currently 50 µm. Therefore, Fines starts at 100% and then decreases to a stable % as the crystals grow.

The full collection of data is only available when observing a real-time measurement on the screen. At the end of each strike, the string of data for times 1, 3, 5, 7, 10, 15, 10, 15, 20, 30, 45, 60, 75, 90, 110, 130, 150 minutes and at the discharge point are stored for a summary of MA, CV, and number count. Thus, extensive historical data are stored for each strike.

The pan stage operators also note the visual quality of the images as the strike progresses and at the end of the strike record their comments. These comments include a general assessment (good/poor, extent of conglomeration, quantity of slurry added, presence of twins, elongation).

5.3.3.4 Alarms

There are several alarm functions that can be set on the software. For each alarm function two levels of alarm can be set viz. pre-alarm (orange) and alarm (red). For each function the alarm and its colour are displayed.

- *Syrup status* determines the number of particles in the syrup before zero time.
- *Number of crystals* at a specified duration after seeding. For instance, the number 5 minutes after seeding is checked.
- Increase in the number of *Fines*. For example, at 60 minutes after seeding, check on the number of Fines and compare with a limit previously established.

5.3.3.5 Additional features of the software

The software has additional features that can be of benefit for analysis of data. These features are further described in Appendix 1.

6 RESULTS AND DISCUSSION

6.1 General comments

The Crystobserver at Condong Mill has been operating since July 7, 2021 and the operators have used the displays and data consistently since that time. Data have been stored since commissioning. However, the analysis of the data has been limited to the period following the visit by the ITECA technician in late July 2022. Data from examining proof samples obtained during two site visits by QUT staff are used to validate the results presented by the analyser.

6.2 Use of the Crystobserver by the pan stage operators

The pan stage operators have shown strong interest in using the Crystobserver since commissioning. The excellent quality of the images is obviously a key factor in ensuring the operators use the display to good effect. Information about recent past experiences is particularly relevant, as they can make decisions on the slurry quantity, graining brix, purity of the blend (if there has been a clear short-term change in the purity of the A and B syrups).

Discussions with the operators has revealed different ways that they use the images and data, including:

- All operators check the image in the first couple of minutes after slurry addition and, once the little crystals can be seen, they are confident the grain is establishing OK, and the prospects look good.
    - The images during that critical stage of survival are very beneficial.
    - The delay time from slurry addition to first seeing the crystals is a key piece of information to them.
    - The operators can see the crystals on the Crystobserver before they would consider taking a proof sample for checking on grain establishment. This assessment is undertaken qualitatively and not quantitatively.
- With the Crystobserver the operators need to proof the pan much less.
    - Certainly, the image is of good quality and so gives the operator a clear indication of what is going on in the pan the whole time (except for any anomalies). Visually the operators are checking on the numbers in the image, and that the crystals have sharp edges and growing.
    - They may also use the system to visually detect the presence or not of conglomerates and estimate if the observed quantity is of concern, so that further action can be taken, if required.
- Check (loosely) on the MA values at different times through the cycle. However, the operators noted that the MA value often increases unrealistically at near the end of the cycle and have attributed this to errors in the MA value when the crystal density becomes high. This ‘theory’ agrees with feedback provided by ITECA.
    - Currently the operators examine a proof sample of the C seed prior to cut out to pan 1 and measure and record the length and breadth of average crystals. A more reliable measure of MA at the end of the cycle would eliminate the need for this operator assessment.
- The operators review the images from the previous three grainings prior to doing the first graining on their shift to provide a quick assessment of what to expect and whether any changes to the procedure have been made or should be implemented.
    - Normally the operator would bring up the three images and quickly work through the sequence of images starting at slurry addition. The key information they look at is how quickly the crystals established, the number of conglomerates and number of crystals.
    - For this review the operators use the images of the previous strikes rather than looking at the recorded MA, crystal numbers etc. Based on the assessment from the review, the main decisions are quantity of slurry and at what conductivity (brix) setpoint. The presence of a lot of conglomerates may suggest graining at a lower purity may be appropriate or at a bit lower brix to increase circulation and improve the dispersion of the slurry into the blend.

- A quick check on the image just after the blend has been brought into the pan is made to ensure that the A and B syrups do not contain crystals. On at least one occasion the presence of crystals allowed the fugal operator to check the cause and it was found that a fugal screen was missing. This may have gone undetected for some additional time which would have caused a major disruption to the A and B massecuite boilings.

6.3 Analysis of Crystobserver data

6.3.1 *Successive runs with the Crystobserver*

Table 2 presents results for 8 successive runs with the Crystobserver in a period of reasonably consistent A syrup purity (72 units). These images are for the massecuite at the end of the cycle i.e., at time of cut out to the C massecuite pan. Dark spots in the images represent bubbles, however, their amount in the images is usually minimal. Crystal conglomeration is observed in almost all these images and is discussed in a later section.

The MA values vary between 153-241 µm, CV between 32.5-40.0% and the Fines between 34.5-43.7% at discharge for these 8 strikes which were undertaken within a period of approximately 28 hours. As a general assessment, it is considered that the first six strikes and the last strike in Table 2 provide a reasonably consistent number count. The second last strike has a slightly lower number count and would likely be classified as "off specification" and warranting corrective action, or at least investigation to see if any change in procedure is immediately needed or await the outcome of the next cycle. It is expected that most operators would take corrective action, e.g., add more slurry, based on the information provided by the Crystobserver for that strike.

Figure 8 presents the trends of MA, CV, and crystal number over time for the same data set. The data points at 180 min represent the discharge point, which varies from strike to strike. These plots may be used to compare the performance between different strikes. Comments on each of the parameters follow.

- The MA data show very consistent profiles with time from time zero till the MA reaches 150 µm. During the early stages (0 – 10 min), where the MA is smaller than about 40 µm, a fast increase in crystal growth is observed. There are two possible explanations viz.
    - There is extremely rapid growth rate owing to the high supersaturation at the point of slurry addition; and
    - The vision system is also picking up the background sludge. Therefore, some inaccuracy is expected for these numbers. It is worth mentioning that the Crystobserver had been only applied to very high purity boilings until now, so having less interference from impurities.

  Towards the end of the strike (> 120 min), large variations in the measured MA occur. This matter has been discussed extensively with ITECA and has been attributed to the higher crystal density at the end of the cycle, resulting in more difficulty to determine crystal size by the software.

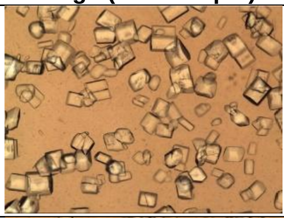
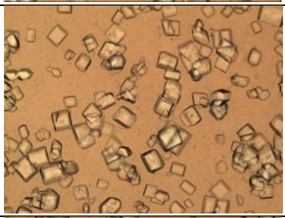
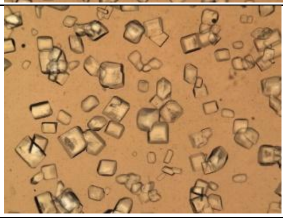
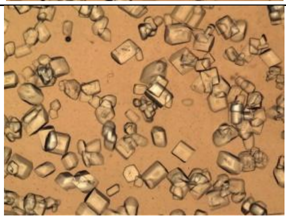
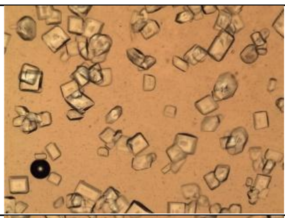
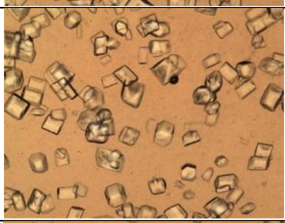
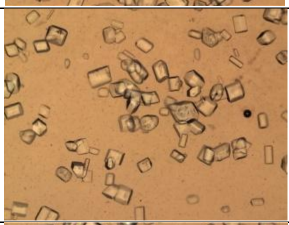
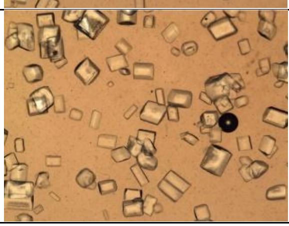
- CV is reasonably consistent among the strikes.

- The crystal number values vary throughout cycles, despite relatively consistent MA numbers. Particularly, the crystal number increases during the period from 10 to about 40-60 minutes and then holds steady (perhaps with a slight decline as time progresses). Two phases to the crystal number would be expected, on the basis that the crystals are measured in a fixed volume in the gap:
    - Similar number count while holding at 18 t (on water and no B syrup feed). This assumes that the number count is reliable from when the crystals are small.
    - Decline in number as the volume in the pan increases from 18 t to 30 t i.e., as B syrup is fed on. That is, there would ideally be the same total number but dispersed in an increasing quantity of massecuite.

However, the observed number count does not follow this pattern. Upon investigation with ITECA, it was concluded that the increase of crystal number observed in Figure 8 is due to the growth of particles that are not detected initially. After these particles grow above a certain threshold, they can be detected by the software, thus giving the false impression that there are more particles than in the early stages.

The fact that the image of the last strike appeared to have a lower crystal density, but the number count was average is unexplained. Of course, a single sample via a proof sampler or via an image from the Crystobserver can always be not representative of the contents of the pan. This emphasises the importance of the pan stage operators making conscious and subconscious assessments of the quality of the grainings from multiple views as the grain development proceeds.

Table 2. Data at the end of a strike extracted from Crystobserver for the period between 11-13/08/22.

Strike #	Date	Image (— = 200 µm)	MA	CV	Fines	Number count
159	11/08 20:40		207.46	34.53%	34.53%	1,127
160	12/08 00:23		158.47	33.24%	37.18%	1,038
161	12/08 03:53		207.53	34.28%	37.13%	937
162	12/08 07:45		211.05	33.84%	35.78%	1,121
163	12/08 12:20		235.23	37.98%	41.58%	1,002
164	12/08 18:04		189.44	37.11%	39.98%	1,082
165	12/08 21:51		152.93	32.49%	43.72%	786
166	13/08 01:24		240.55	40.03%	40.78%	1,034

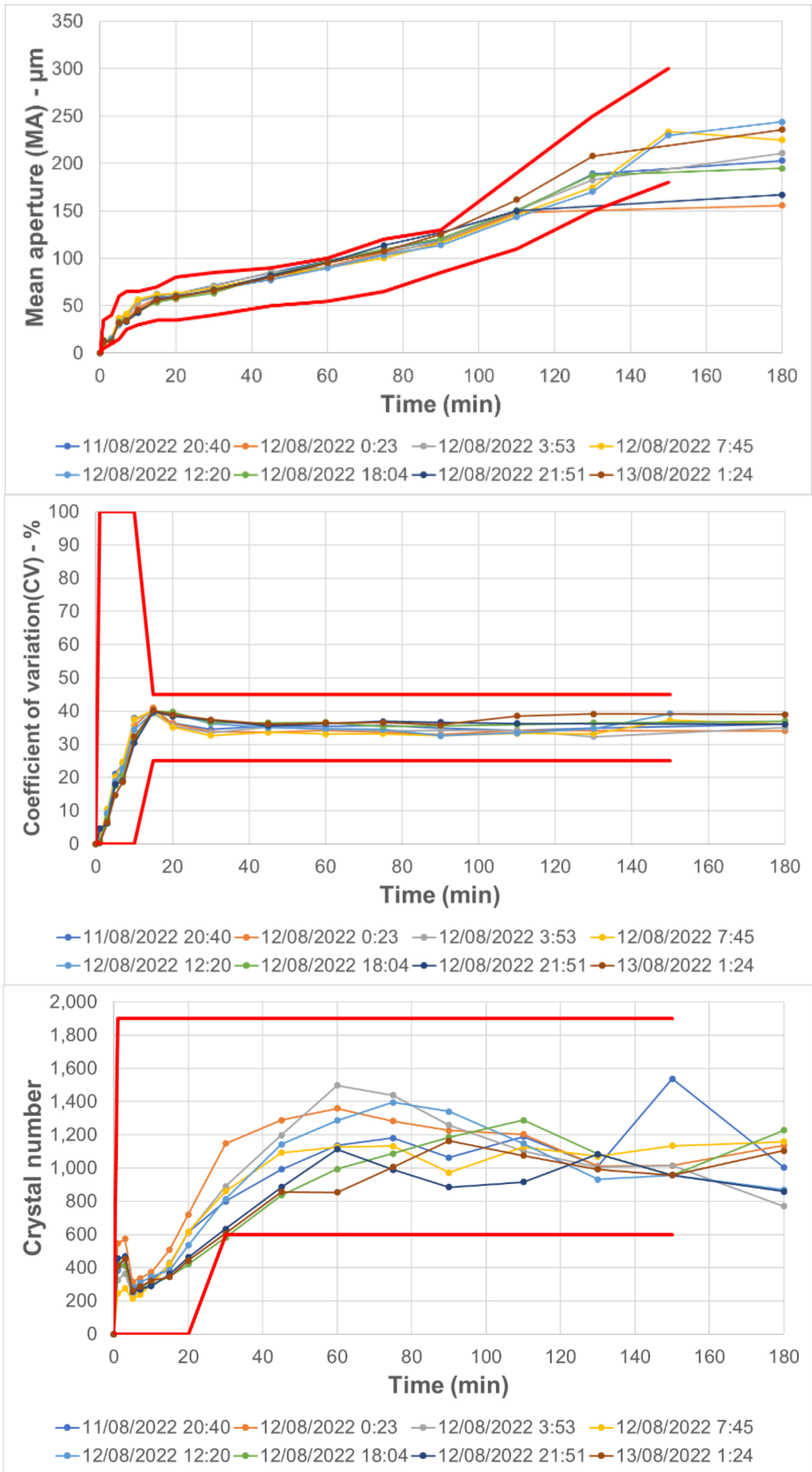


Figure 8. Plots of MA, CV, and crystal number for the 8 strikes analysed. ***Upper and lower limits for alarms in red. Note: 180 min means the discharge point, which varies according to the strike.***

6.3.2 *Low and high purity seeding*

Table 3 presents data for two different boilings, one with a high purity graining blend (70 purity) and the other one with a low purity blend (68 purity). While the crystal numbers may start lower on the low purity, similar or even higher crystal numbers were present at the end of the strike (Figure 9). This trial indicates that a successful C seed production could be achieved by reducing the feed purity from 70 to 68. The financial benefit of this reduction is discussed in Section 6.5.

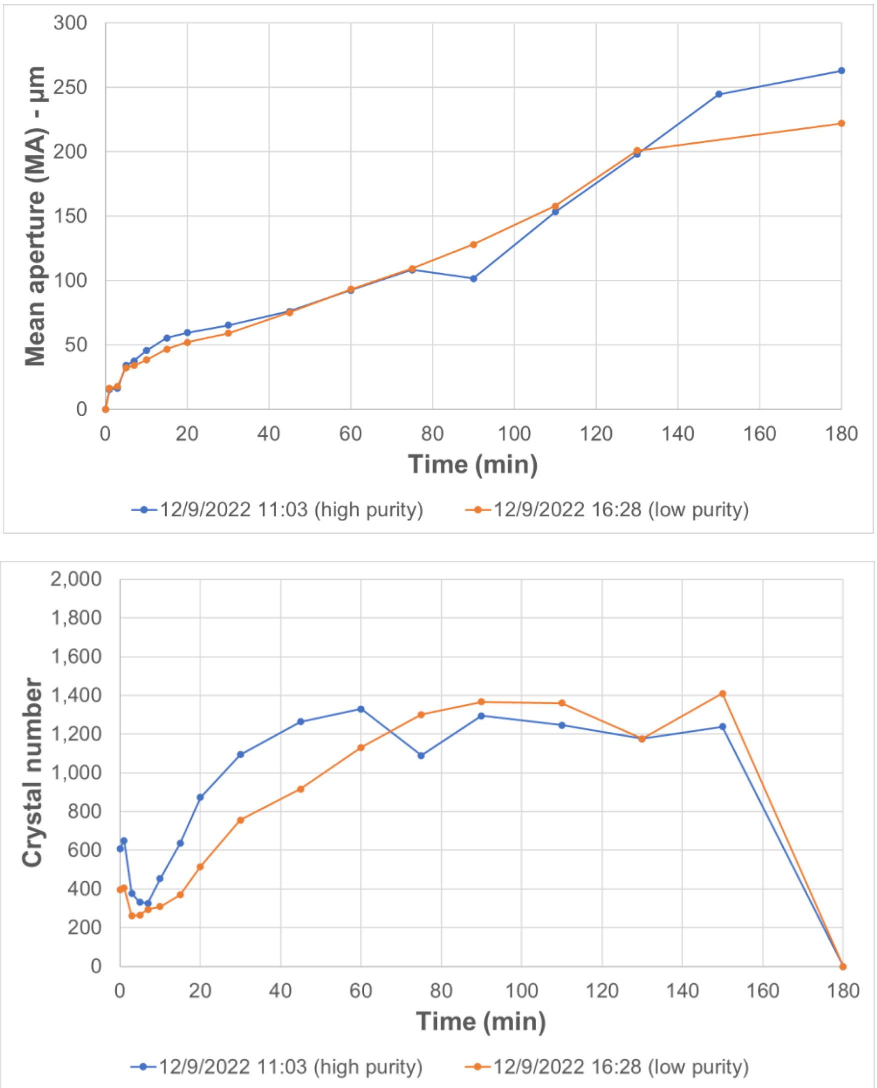
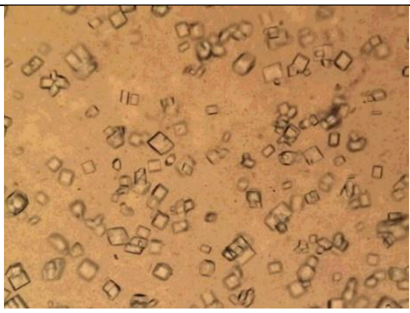
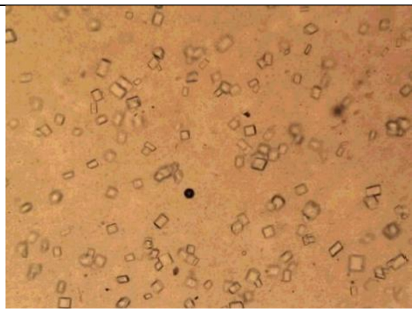
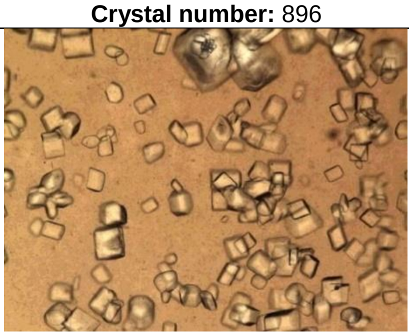
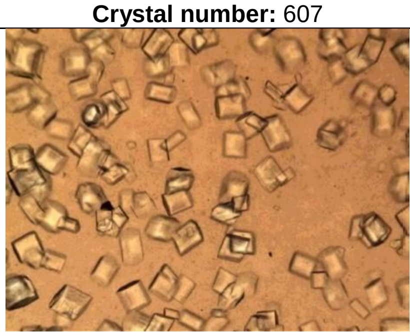
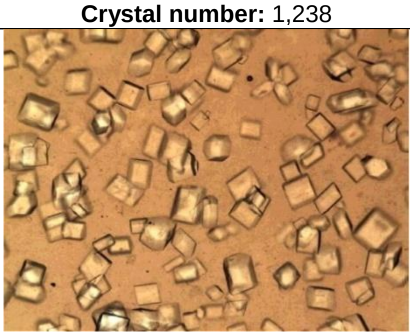
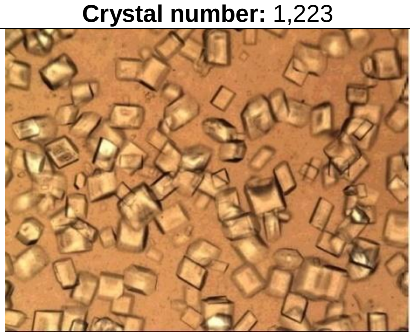
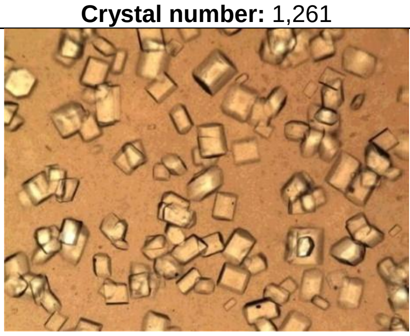
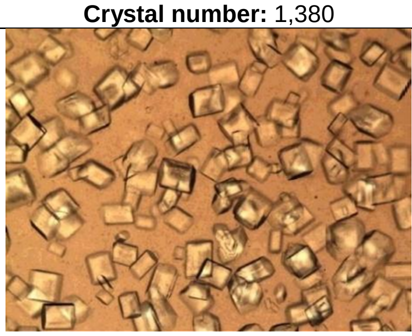


Figure 9. Plots of MA and crystal number for the low and high purity strikes analysed. ***Note: 180 min means the discharge point, which varies according to the strike.***

Table 3. Data at several periods of two strike examples (low and high purity feed) extracted from the Crystobserver.

Time after seeding	12/09/22 12:19 (high purity)	12/09/22 16:28 (low purity)
30 min	 **MA:** 66.43 µm **CV:** 34.64% **Crystal number:** 896	 **MA:** 62.95 µm **CV:** 36.53% **Crystal number:** 607
90 min	 **MA:** 109.64 µm **CV:** 33.54% **Crystal number:** 1,238	 **MA:** 132.52 µm **CV:** 37.86% **Crystal number:** 1,223
130 min	 **MA:** 204.86 µm **CV:** 37.72% **Crystal number:** 1,261	 **MA:** 202.40 µm **CV:** 37.43% **Crystal number:** 1,380
Discharge	 **MA:** 263.53 µm **CV:** 39.96% **Crystal number:** 1,187 (229 min)	 **MA:** 211.09 µm **CV:** 38.28% **Crystal number:** 1,451 (210 min)

6.3.3 *Comparison of data obtained by Crystobserver and digital microscope*

The data obtained by the Crystobserver were compared to assessments made manually on proof samples under a laboratory microscope when QUT staff visited the site (12/9/22). Crystal number count data and images are shown in Table 4 and Table 5. QUT manufactured very thin stainless steel microscope slides in order to allow a thin layer of the mother molasses to be examined and individual crystals to be counted. The slide was 0.12 mm thick and provided a viewing hole of 13 mm diameter. Proof samples were taken from pan 5, placed on the microscope slide and smeared to the thickness of 0.12 mm. Care was taken to not overfill or underfill the hole and ensure any excess sample was retained within side slots of the microscope slide. The digital microscope (Inskam 315 - 12 MP camera) allowed photographs to be taken of various sections of the sample. Figure 10 shows a photograph of the slides and the digital microscope. The crystal number per unit volume was determined following the methodology below:

1. Original image of the sample was cropped into 4 equal parts, where one part of better quality was used for the measurements,
2. Using the software ImageJ, the crystals were counted in that section. Conglomerates were considered as individual crystals.
3. The counted number of crystals in that section was then multiplied by 4.
4. The number of crystals per unit volume was determined by dividing the number count by the visible area of the image (previously determined to be 20.4 mm^2) and the thickness of the slide (0.12 mm).

There is a risk of a large experimental error in determining the crystal number using the digital microscope if the sample overfills the hole and increases the thickness (and volume) of the sample.

It can be observed that the crystal number per mm^3 (number in parentheses) calculated from the Crystobserver number count cannot be directly compared to the one manually determined using the digital microscope (Table 4 and Table 5).This can be probably attributed to (i) the method of detecting crystals by the Crystobserver software and (ii) uncertainties and limitations in the resolution of the digital microscope. Nevertheless, the general trend in crystal number between the samples is reasonable. The numbers from the Crystobserver appear to provide a reasonable estimate of crystal numbers in relative terms when comparing numbers strike to strike.

Figure 10. Photograph of the slide (left) and the digital microscope (right).

Table 4. Comparison between data from the Crystobserver and samples collected and measured in a digital microscope (12/09/22) – Part 1.

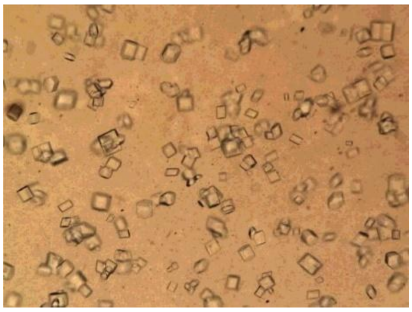
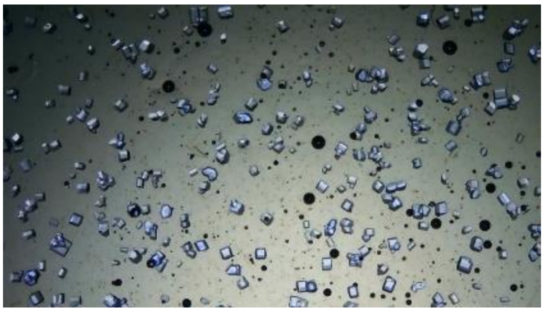
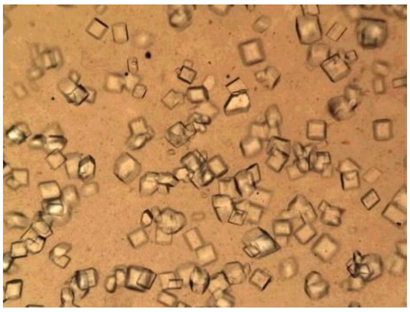
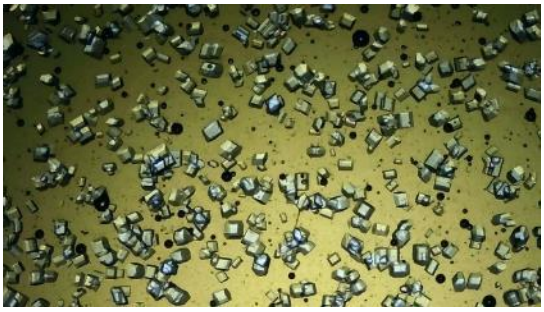
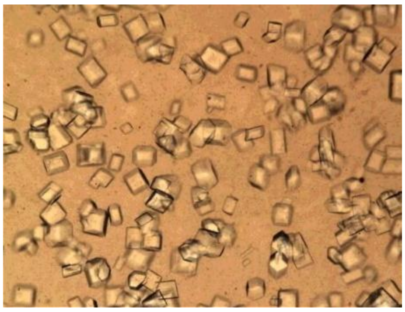
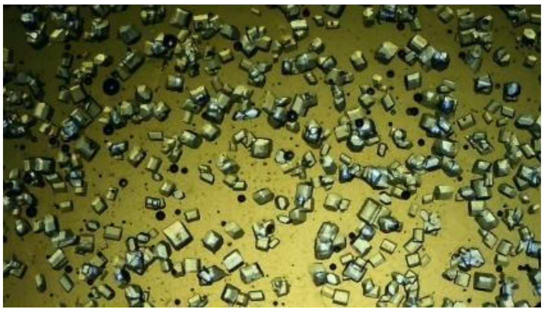
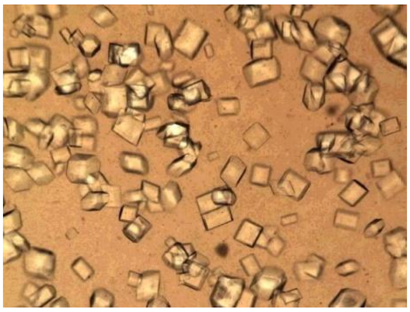
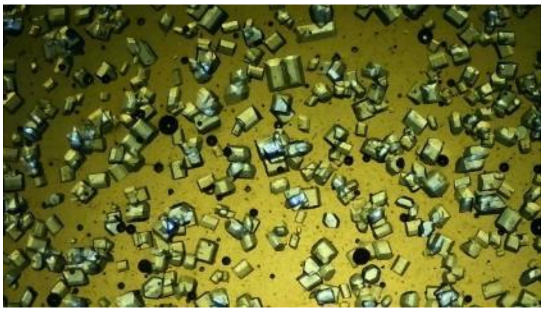
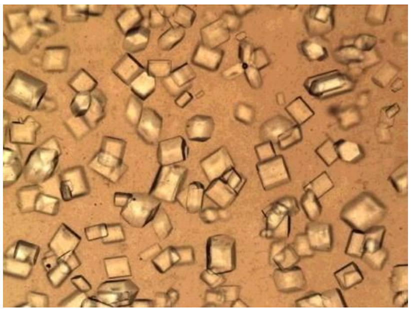
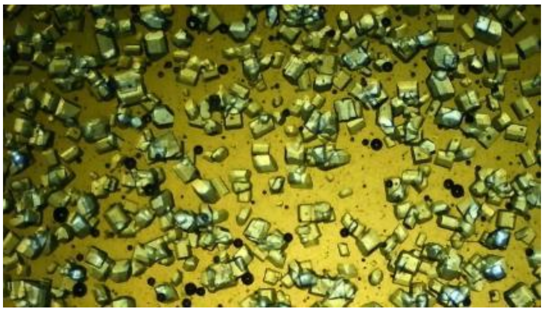
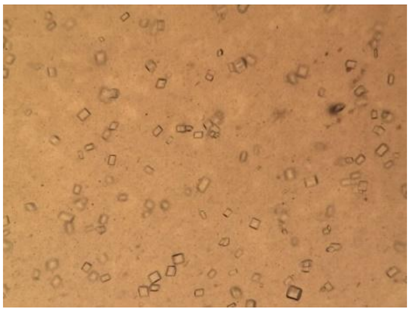
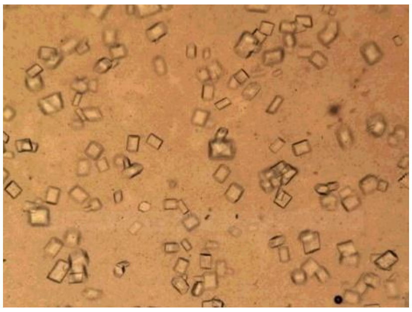
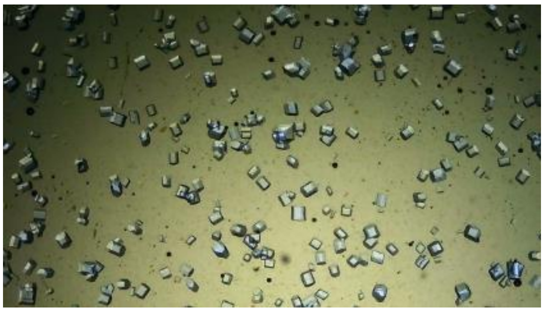
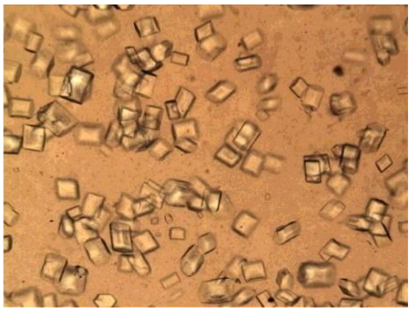
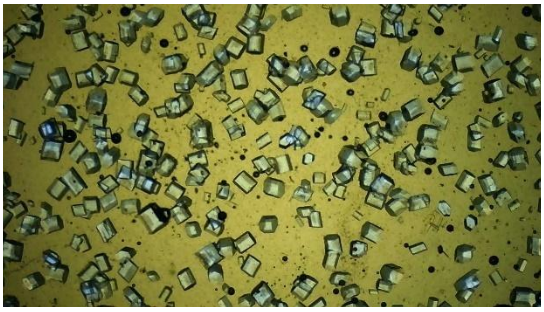
Date	Crystobserver Image	Crystal number	Microscope Image	Crystal number (number/mm³)
12/09/22 12:52		899 (658/mm³)		336
12/09/22 13:13		1,142 (836/mm³)		450
12/09/22 13:24		1,332 (975/mm³)		454
12/09/22 14:02		1,285 (941/mm³)		355
12/09/22 14:30		1,243 (910/mm³)		442

Table 5. Comparison between data from the Crystobserver and samples collected and measured in a digital microscope (12/09/22) – Part 2.

Date	Crystobserver Image	Crystal number	Microscope Image	Crystal number (number/mm³)
12/09/22 16:55		482 (353/mm³)		132
12/09/22 17:20		773 (566/mm³)		263
12/09/22 17:49		1,151 (842/mm³)		370

6.3.4 *Crystal growth rates*

The growth rates of crystals from 10 to 50 microns, 50 to 100 microns and 100 to 150 microns were calculated from the Crystobserver data presented in Figure 8. The growth rates in each of the increments provide insight into the consistency of the mother molasses supersaturation for the slurry addition point and for run up of the pan. Of course, other factors such as variations in the blend purity (based on the available laboratory data) and freshness of the cane supply would affect the growth rates. Temperature would also be a factor but ideally the head space vacuum is reasonably consistent for all the cycles as per the defined C seed production recipe.

Examination of the growth rate data in Table 6 shows:

- A very high growth rate in the size range 10 to 50 µm. As a check an estimate of the crystal growth rate was made based on the correlation provided by Miller & Beath (1999) for: 70°C, RS/ash 1.0, dry substance 85.7, purity 70; and is equal to 128 µm/h. Therefore, there is some discrepancy in growth rate for the 10-50 µm range. This could be attributed to the low sensitivity of measurement for small particles (< 40 µm), as discussed previously.

- The growth rates in the following two phases (typically 60 to 70 µm/h) are substantially lower than for the initial growth phase and are more realistic in terms of the growth expected to produce a C seed of mean size 200 µm after a growth period of say 2.5 h following slurry addition.

The growth rate data as presented in Table 6 could be included in a daily report to the production supervisor. A quick scan of the range of values for each strike of C seed production for the previous 24 h would quickly highlight if a problem occurred in C seed production. Of course, such problems would very likely have been observed by the pan stage operator and corrective action taken. The growth rate data does provide a strong indication of the selected brix of the mother molasses for grain establishment from slurry and for the run-up conditions (or some other factor e.g., stale cane). It is considered that the data in Table 6 for each of the increments show a reasonable level of consistency in the C seed production methods. There is no gross outlier in any of the increments of growth rate.

Table 6. Growth rate calculated for the 8 strikes evaluated from 11-13/08/22.

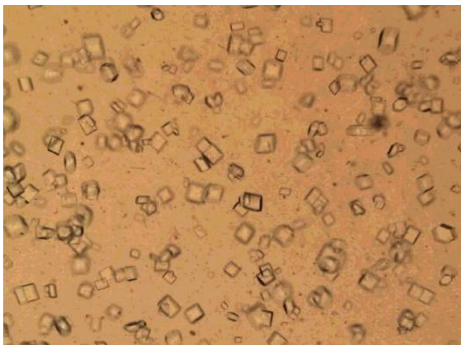
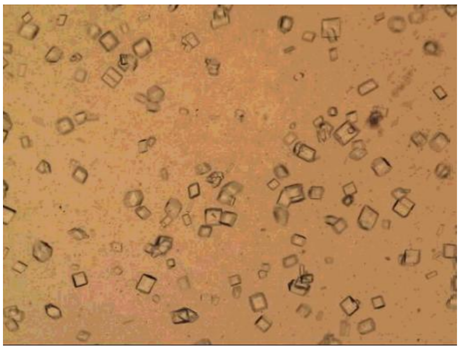
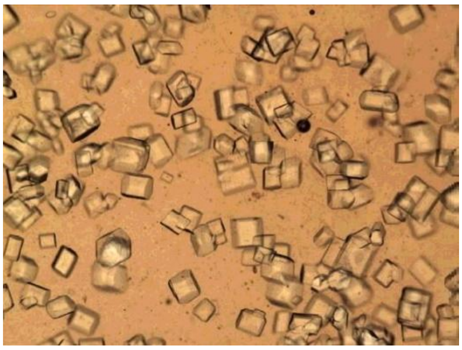
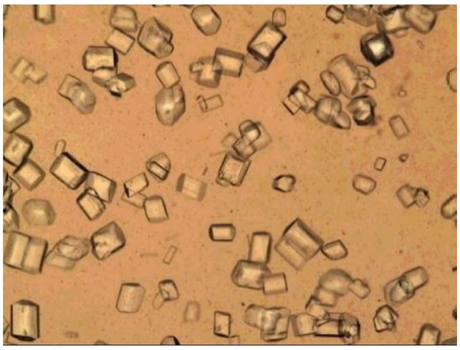
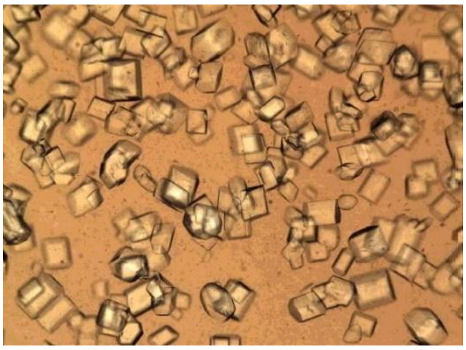
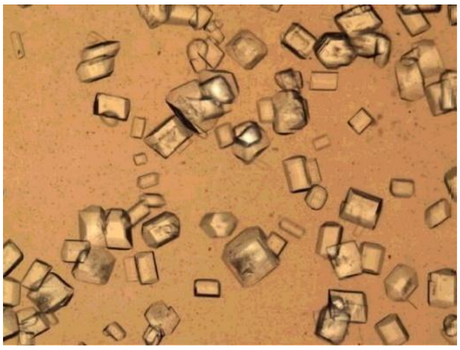
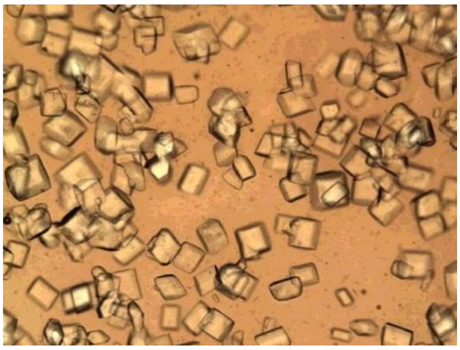
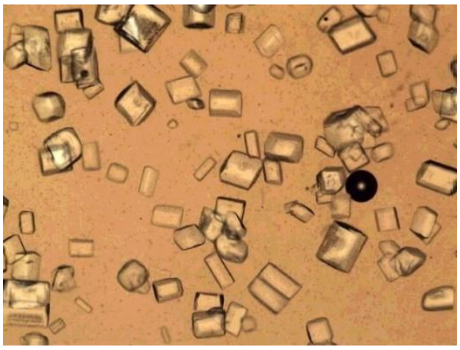
Date	Growth Rate (10-50 µm) µm/h	Growth Rate (50-100 µm) µm/h	Growth Rate (100-150 µm) µm/h
11/08 20:40	284.1	50.6	70.0
12/08 00:23	242.0	54.6	71.4
12/08 03:53	279.5	47.3	78.2
12/08 07:45	285.1	40.3	77.9
12/08 12:20	217.2	54.0	68.9
12/08 18:04	212.6	60.9	70.5
12/08 21:51	197.6	65.8	62.1
13/08 01:24	218.7	58.0	92.9

6.4 Use of the Crystobserver for troubleshooting

Table 7 shows a series of images taken for two C seed strikes. Note the series shown on the right was intentionally selected as an example when the C seed quality was poor with respect to established crystal numbers. Thus, the system allows the operator to clearly distinguish between typical and poor-quality batches.

In possession of this real time data, the operator may take decisions to improve the rate of crystal growth and crystal numbers. They may decide which changes to make for the next cycle, such as adding higher volume of slurry or change the graining point. The next graining point could be at a higher dry substance on the basis that the previous graining could have been at a low supersaturation or, instead, it could be at lower dry substance on the basis that circulation in the pan was poor and the slurry did not mix evenly through the blend. Comparison of MA data with the data from previous cycles would guide the operator on which corrective action would be appropriate. Hence, it is common that the operator makes day-to-day decisions to achieve consistency in graining outcomes, while long-term adjustments to the process are decided by the production manager.

Table 7. Crystobserver images of two cycles: typical (left) and poor (right).

Time after seeding	23/08/22 20:55	13/08/22 02:34
30 min	 **MA:** 66.79 µm **CV:** 43.42% **Crystal number:** 917	 **MA:** 65.48 µm **CV:** 37.69% **Crystal number:** 628
90 min	 **MA:** 118.06 µm **CV:** 37.26% **Crystal number:** 1,333	 **MA:** 123.83 µm **CV:** 35.80% **Crystal number:** 1,109
130 min	 **MA:** 179.65 µm **CV:** 34.33% **Crystal number:** 1,382	 **MA:** 202.15 µm **CV:** 38.28% **Crystal number:** 1,019
Discharge	 **MA:** 212.20 µm **CV:** 36.83% **Crystal number:** 1,362	 **MA:** 240.55 µm **CV:** 40.03% **Crystal number:** 1,034

6.4.1 *Presence of conglomeration*

During QUT visits to Condong Mill, significant conglomeration of crystals was observed in the Crystobserver images. Data for 4 cycles at random were analysed, and all show conglomerates. These images are presented in Table 8. These data were used as a starting point for troubleshooting of the process to try to reduce conglomeration.

Possible causes of conglomeration, particularly in the growth stage up to 50-60 microns, are:

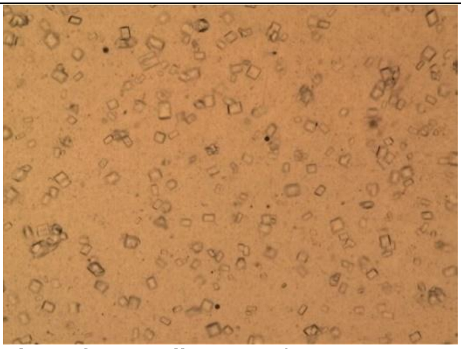
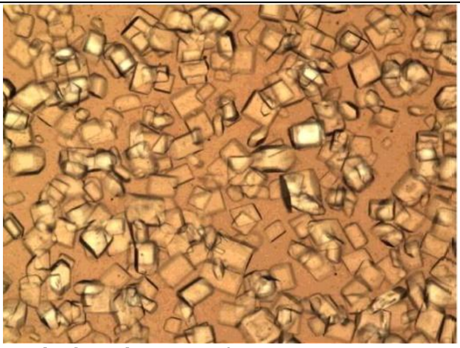
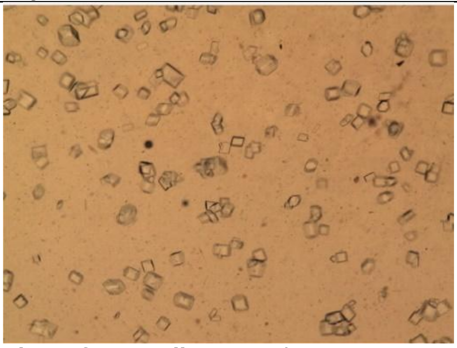
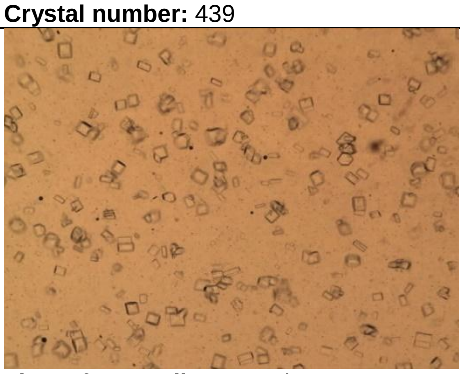
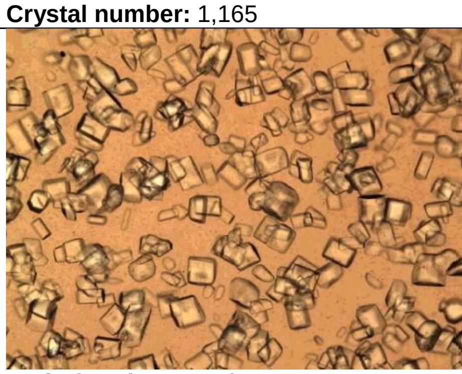
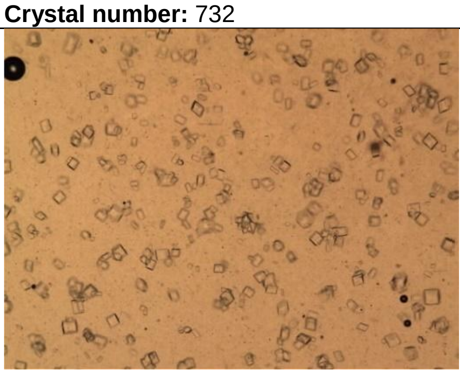
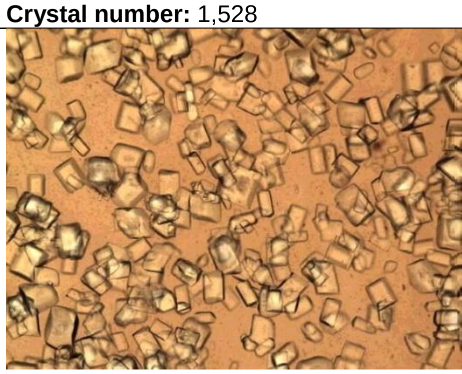
- Blend when slurry added is too high in purity,
- Circulation in the pan is poor,
- Adding the slurry at too high brix,
- Adding the feed syrup/molasses too early.

This information was discussed with the engineers at Condong Mill and three measures were trialled:

- Extend the time for holding the pan on balance water after graining from 5 minutes to 30 minutes.
    - This modification to process showed a noticeable improvement in the reduction of conglomeration and has since been adopted by all pan stage operators as standard practice to good effect.
- Reduce the purity of the graining blend. The blend of A syrup/B syrup was changed from 14/4 to 8/10.
    - The reduction in purity of the graining blend reduced the presence of conglomeration in subsequent strikes confirming the suspicion that the graining blend was too rich. Variation in cane quality requires continual monitoring and adjustment of the blend of A syrup/B syrup to achieve the desired blend purity. The information from the Crystobserver allows the pan stage operators to initiate these discussions with the production managers prior to receiving results from the control lab which has a considerable lag. (Condong conduct true purity assessment of pan stage products on a 24 hour composite sample).
- Introduction of slurry at a lower brix (higher conductivity).
    - Pan stage operators trialled introducing slurry at approximately 5 -10 units of conductivity higher than previously to promote better mixing of the slurry due to the noted poor circulation within the pan. This measure has also reduced the presence of conglomeration with no observed detrimental impact on the success of graining.

No quantitative data were obtained to assess the effects of these three measures on conglomeration.

Table 8. Crystobserver images containing conglomeration: at 30 minutes after slurry addition (left) and end of cycle (right).

09/08/22 13:50	 **Time after seeding:** 29 min **MA:** 64.02 µm **CV:** 41.50% **Crystal number:** 720	 **End of cycle:** 197 min **MA:** 257.23 µm **CV:** 42.43% **Crystal number:** 1,643
12/08/22 18:04	 **Time after seeding:** 24 min **MA:** 59.87 µm **CV:** 38.67% **Crystal number:** 439	 **End of cycle:** 128 min **MA:** 187.29 µm **CV:** 37.18% **Crystal number:** 1,165
14/08/22 01:50	 **Time after seeding:** 25 min **MA:** 60.86 µm **CV:** 39.26% **Crystal number:** 732	 **End of cycle:** 101 min **MA:** 122.44 µm **CV:** 32.59% **Crystal number:** 1,528
14/08/22 22:24	 **Time after seeding:** 25 min **MA:** 60.86 µm **CV:** 38.60% **Crystal number:** 781	 **End of cycle:** 158 min **MA:** 211.14 µm **CV:** 36.73% **Crystal number:** 1,557

6.5 Benefits of using the Crystobserver in Australian sugar factories

Production of C seed of consistently high quality assists the control of all subsequent operations on the pan and fugal stations. Still, the main advantages of the Crystobserver are to assist the operator of the pan stage in:

- General troubleshooting,
- Not having to proof the pan and check the sample under a microscope,
- Allowing them to pick up anomalies very early, e.g., very poor grain establishment,
- Providing information that allows them to decide whether a change in procedure is required for the next C seed production, e.g., to change the quantity of slurry used, to change the brix at slurry addition,
- Observations on elongation, conglomeration,
- Improving the technique for graining and promoting standardization among shifts,
- Providing information (images and key parameters) to an operator to review at the start of his/her shift regarding grainings for previous recent shifts, thus guiding decisions on any adjustments to be made to the graining recipe.

For the financial analysis for installation of the Crystobserver, only an improvement in raw sugar recovery was considered and is described in the following paragraph. While there are additional benefits that may lead to additional positive financial outcomes, these are difficult to quantify. For instance, financial benefits to throughput, steam consumption and water consumption are more difficult to quantify and would depend on the factory's installed capacity, use of bagasse, etc. Improvements in the quality of the product sugar from the factory may also be achieved through greater consistency of the crystal size of the C sugar magma.

The financial analysis is undertaken on the basis that there is available capacity in the C seed pan to accommodate the slightly lower growth rate from using a 68 purity blend instead of a 70 purity blend. Based on the blend being 40% of the C massecuite quantity at drop, a reduction in C massecuite purity of 0.8 units is expected, with subsequent reduction in final molasses purity of 0.24 units (with all processing arrangements in the crystallisers being unchanged). As a side benefit it is generally accepted that fewer conglomerates are formed when a lower purity blend is used. The assumptions for the financial analysis are summarised in Table 9.

Table 9. Assumptions for the financial analysis

Parameter	Assumed value	Comments
Purity of graining blend	Reduce from 70 to 68	
Graining blend/C massecuite	0.4	
Reduction in C massecuite purity resulting from use of a lower purity graining blend	0.8	
Reduction in final molasses purity	0.24	Assume reduction in final molasses purity/reduction in C massecuite purity = 0.3.
Fraction of season that improved recovery is obtained	0.5	
Sugar production	99.2 purity, 0.27% moisture	
Final molasses base conditions	45.5 purity 3.2% on cane 76 dry substance	Average final molasses conditions in Australian factories reported by Broadfoot (2019).
Sugar price per t, AUD	500	
Molasses price per t, AUD	120	
Discount rate	12%	
Period	10 years	
Purchase price for Crystobserver, AUD	67,000	Price as of Sep/22 (1 EUR = 1.50 AUD). Includes commissioning by ITECA Engineers (AUD 8,000) and freight (AUD 5,000). The installation of two systems on the same order and commissioning at the same time adds an extra AUD 24,000.
Installation costs at the factory, AUD	10,000	For installation of flange on the pan, supply of water, air and power, supply of DCS data to Crystobserver.
Maintenance costs	3% p.a. of purchase price	

For a factory processing 1.5 M tonne cane per annum the NPV is AUD 86,000, IRR 36% and the payback period is three seasons. As each factory has only one C seed pan for grain establishment, the financial return is strongly dependent on the throughput rate of the factory, as shown in Table 10.

Table 10. NPV, IRR and payback period estimated for different cane crop sizes

Cane crop, t	NPV, AUD	IRR, %	Payback period, seasons
500,000	-30,000	1.4	-
1,000,000	28,000	20	5
1,500,000	86,000	36	3
2,000,000	144,000	50	2

6.6 Maintenance of the Crystobserver

No preventative maintenance for the microscope and lens is required and trouble-free operation is expected for several years. The original Crystobservers have been in use for approximately 8 years. All software fixes (rarely required) can be completed remotely by ITECA.

One issue that can arise is calcium build up on the sight glass or on the glass at the end of the light tube (from hard water). This can be very difficult to clean and glass replacement may be necessary. At this stage there is no deterioration in the clarity of the image at Condong Mill (where condensate is being used).

The two main repair items for hardware are the sight glass and the seal. ITECA advised that Condong staff should be able to undertake the seal replacement as the light mount motor holds its critical positioning. With the sight glass, the main requirement is to ensure the same gap is provided between the light tube and glass at the reference positions. Again, adequate instructions can be provided by ITECA to allow Condong staff to complete the repairs.

As pointed out by ITECA, the most important thing is that, if the pan is to be left with massecuite covering the sight glass, the Crystobserver should be left operating. This is mainly to stop crystal from building up on the light tube which could damage the seal when the light tube is retracted.

7 Applications of the Crystobserver in sugar factories

7.1 Recommendations for installation and commissioning in Australian factories

The staff at Condong Mill installed the Crystobserver, supervised by ITECA staff remotely. While this method was satisfactory, the recommended approach would be to have an engineer from ITECA onsite for this process.

A water filter with maximum size of 110 µm is recommended by ITECA for the washing system, to prevent impurities from reaching the sight glass. Also, the vortex cooler for the cooling system was provided by ITECA with the system. The flanges (mild steel) were provided by Condong, according to specifications supplied by ITECA.

Suggestions were made to ITECA that a customised data record should be included on the Vacuum Pan Historical table. Currently there is a single column for comments to be inserted by the operator such as strike number, quantity of slurry, general assessment of graining quality (e.g., good). It is recommended to simplify the current table to store only the data at discharge. This will make room for the following to be added into separate columns which will be easier for extraction into Excel and subsequent data analysis if required. Data to be included in the columns are strike number, blend details (e.g., 10/8), slurry quantity, conductivity at graining, quality, anomalies. Ideally the anomalies column would be slightly wider than the other columns to hold information such as comments on conglomeration, other observations.

7.2 Use of the Crystobserver by factories

When first commissioned in a new factory, it is expected that the operators will follow similar procedures to those described in Section 6.2. The operators should compare the results with those from their microscope at the commissioning to confirm the reliability of the system. Additionally, they should be encouraged to leave comments at the end of a strike in the Crystobserver system. These comments are useful for the other operators to assess when they come on shift and to review historically, if needed. Linking the DCS information to the Crystobserver is also an important feature of this system, which may be used to analyse historical data.

At this stage, a range of ideal operating conditions was established for MA, CV and crystal number and alarms activated in the software, so that the operators are alerted about potential variations in the process. The long-term benefit of these alarms is yet to be determined as the number of process changes that can be made by the operators, at least following the slurry addition, for the C seed production step is relatively limited.

7.3 Shortcomings

The observed uncertainty in particle size measurements at the initial stages of seeding, when the MA is < 40 µm is a limitation of the system. This is likely to be due to the difficulty in detecting crystals by the software because the colour of the background. Additionally, as confirmed by ITECA, the system shows limitations in accurately measuring the MA at the end of the strike (time > 120 min), when there is high crystal density in the screen. While some adjustments to the rolling average that calculates MA could be implemented, these would not be a definite solution to the issue. While these shortcomings do not represent a major disadvantage for C seeding applications, they should be considered for new applications of this system. This matter was not fully addressed by ITECA at the time of finalising this report. It is noted that there are many refineries using the system so presumably the difficulties associated with estimating MA in massecuites having high crystal density has been resolved in these instances.

7.4 Potential additional uses of the Crystobserver

Besides its use in C seed production, there is potential to implement the Crystobserver on final sugar product (A and B massecuite) as ITECA has mentioned the system also works well on 0.85-1.0 mm crystals. However, the shortcomings discussed in the previous section should be considered if there is interest in accurate measurements of the final crystal size for these applications. Nevertheless, the system could be applied to assist the operator in early detection of fine grain and to monitor the consistency of growth.

In addition, the Crystobserver would be well suited for the magma washing step where the condition to cease dissolution would be more clearly defined and greater consistency of the quality of the washed magma should be achieved (crystal size typically reduced by 100 µm during washing).

7.5 Alternatives to the Crystobserver

Two competing image monitoring systems were identified and are briefly discussed here.

7.5.1 *Pixact Crystallization Monitoring (PCM)*

The Pixact Crystallization Monitoring (PCM) technology is designed for the online measurement of crystallisation processes (Figure 11 and Figure 12) (Hannu et al. 2019). PCM provides a live camera view of the crystal suspension and detailed measurement data on crystal characteristics, such as size distribution, morphology, and concentration. Upon communication with the company, they proposed a back-lit system due to small size of crystals in the C seed pan. The system was quoted in 2020 at AUD 94,000 (1 EUR = 1.50 AUD), including the measurement system, a computer and the installation and commissioning on site by a Pixact engineer.

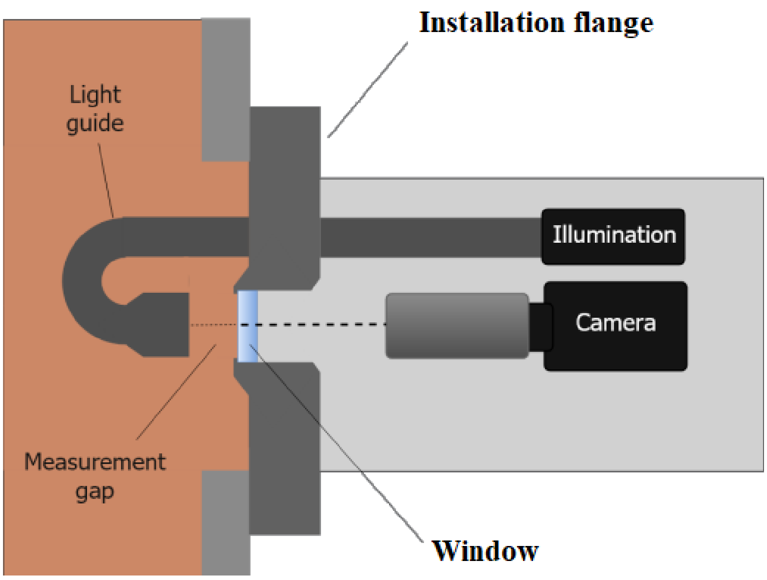


Figure 11. Illustration of the back-lit setup and imaging principle (Hannu et al. 2019).

Figure 12. Installation on the boiling pan sight glass (left) and example image of the crystal suspension (Hannu et al. 2019).

Pixact also supplies a nonintrusive measuring system which involves three lights directed onto the sight glasses at predetermined angles to identify the individual crystal faces. The system seemed to be less suitable than the backlit unit for applications in raw sugar factories.

7.5.2 *Canty SugarScope*

As noted on the JMCanty website (JM Canty 2022) the Canty SugarScope is a high-speed video system that captures and displays live video images of sugar crystals in a sugar pan under process conditions for blur-free, flicker-free process monitoring (Figure 13 and Figure 14). This system has a fixed light tube. JM Canty claims that the SugarScope views particles as small as 1 micron, besides monitoring MA and CV. Data reported includes intensity, major/minor diameter, aspect ratio, perimeter, area, volume, and circularity. Outputs are available on a minute-to-minute basis. The system cost is expected to be around AUD 50,000.

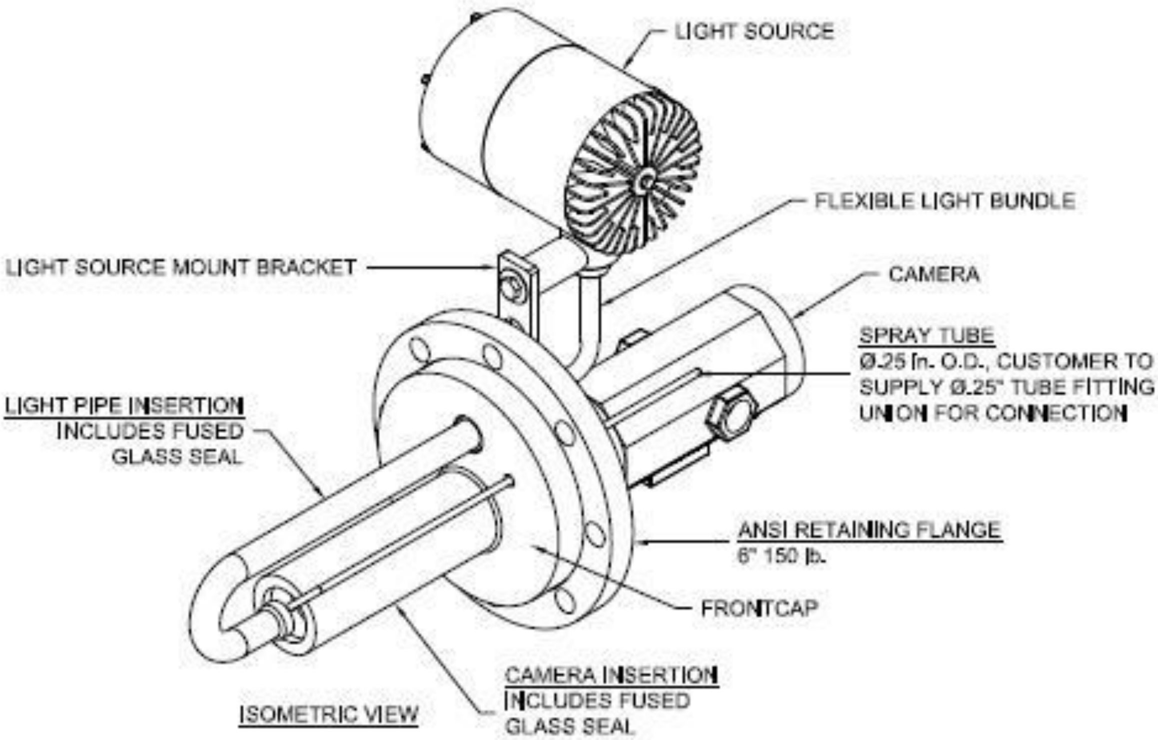


Figure 13. Drawing of the SugarScope insertion (JM Canty 2022).

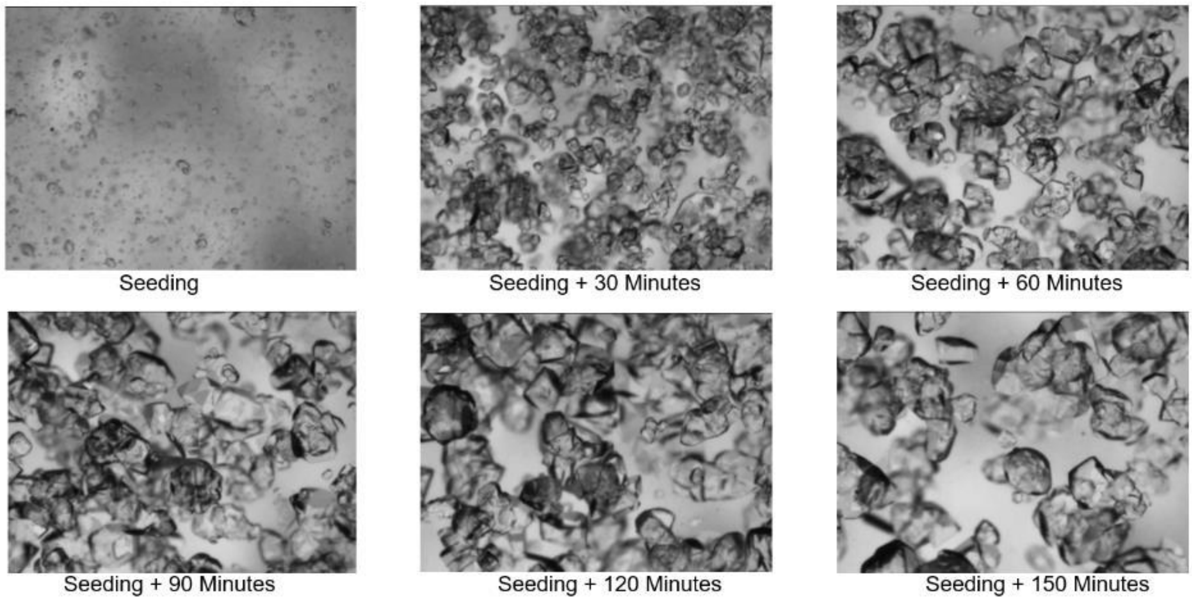


Figure 14. Example of crystal images from the SugarScope at various time points from initial seeding (JM Canty 2022).

7.5.3 *Summary*

The two systems described in this section have similar characteristics and relatively similar prices to the Crystobserver. One aspect of consideration is the quality of the crystal images shown in the examples above (Figure 12 and Figure 14) from the two suppliers. The images obtained by the Crystobserver appear to be sharper and provide good clarity. A detailed technical comparison of these alternatives has not been made at this stage. Additionally, no information has been obtained regarding the possibility of using TeamViewer to monitor the performance of these systems, which has been a significant benefit of the system provided by ITECA.

8 CONCLUSIONS

The analysis of data collected by the Crystobserver has demonstrated that the system provides consistent and reliable images during the C seeding process. Importantly, the Crystobserver requires little to no maintenance and the quality of its images is excellent.

The evaluation of several runs has shown that the crystal size data has very consistent profiles with time, from time zero till it reaches 150 µm. During the early stages, where the size is smaller than 40 µm, a rapid crystal growth was observed. This is likely to be caused by inaccuracies with the vision system because of the background slurry. Similarly, towards the end of the strike (> 120 min), large variations in the measured mean size occur. This variation has been attributed to the higher crystal density at the end of the cycle, making it more difficult for the software to determine crystal sizes of individual crystals.

The system can store historical data for easy reference and has been used by the pan stage operators to good effect for troubleshooting and making decisions with respect to improved operation. The Crystobserver was used in one instance to assess the difference in graining and crystal growth rates when using a blend of 68 purity instead of 70 purity. The result showed no detrimental effect from the lower purity blend with respect to MA or crystal numbers. The use of a lower purity blend does provide scope to reduce the C massecuite purity. In this scenario, a reduction in final molasses purity would be expected and more sugar product would be recovered. The financial return is strongly dependent on the throughput rate of the factory and, for a factory processing 1.5 M tonne cane per annum, the NPV is estimated at AUD86,000, IRR 36% and the payback period three seasons.

9 RECOMMENDATIONS FOR FURTHER RD&A

The Crystobserver system should be evaluated in other pans:

- **Magma wash pan:** There is demand for additional R&D to obtain further understanding of the washing step in the magma preparation pan with the aim to improve consistency of operation. The key information is the selection of the end point of washing, to avoid excessive dissolution of crystals and improve the consistency in the number of crystals retained after washing.

- **A and B massecuite pans:** Early detection of fine grain would be a significant improvement to the operation of A and B massecuite pans. This information would benefit the achievement of consistent crystal growth. It should also be possible to provide estimates of crystal growth rates at different stages through the run-up phase. Further communication is required with ITECA to determine how reliable estimates of MA can be provided when crystal density is high.

10 PUBLICATIONS

No publications have been prepared at the time of completing this report.

11 ACKNOWLEDGEMENTS

Several staff at Condong Mill contributed to the project and their assistance is greatly appreciated. Special thanks are extended to the pan stage operators (Peter, Rob, John, Eden and Craig).

Lilian Sabatté of ITECA (France) provided remote support through the commissioning, signal conditioning and evaluation phases of the project. Lilian also visited the site between 25-28 July 2022 to inspect the equipment and conduct further adjustments. Beneficial discussions were also held with Norbert Duc and Silvere Compos.

Sunshine Sugar thanks Sugar Research Australia for funding the project.

12 REFERENCES

Broadfoot, R. (2018). Assessing the efficiency of sucrose recovery from final molasses. Proceedings Australian Society Sugar Cane Technologists, 41: 194-204.

Hannu, E., Markus, H., Craig, M. (2019). Online measurement of sugar crystallization with a portable non-intrusive instrument, 78th Annual Meeting of Sugar Industry Technologists.

JM Canty – Sugar industry brochure. [online] Available at: https://www.jmcanty.com/product/canty-brochure [Accessed 19 Oct. 2022].

Miller, K.F. and Beath, A.C. (1999). Crystal growth rates in high grade vacuum pans, SRDC Report - SRI.

13 APPENDIX

13.1 Additional features of the system

In this section, some of the additional features of the system, particularly with respect to the software, are described. It is worth mentioning that the software has been customised as per suggestion by Condong Mill staff and QUT so that the more relevant information is displayed in an easy manner for the C seed application. ITECA has indicated that the software may be further modified according to each client's needs.

Real time and trend historical:

There are two options available for the user for historical trends, one that shows the real time trends, and another one that shows the trends for historical data. In this section the trends for different parameters, including DCS data (if available), across periods of time, including different seasons is provided.

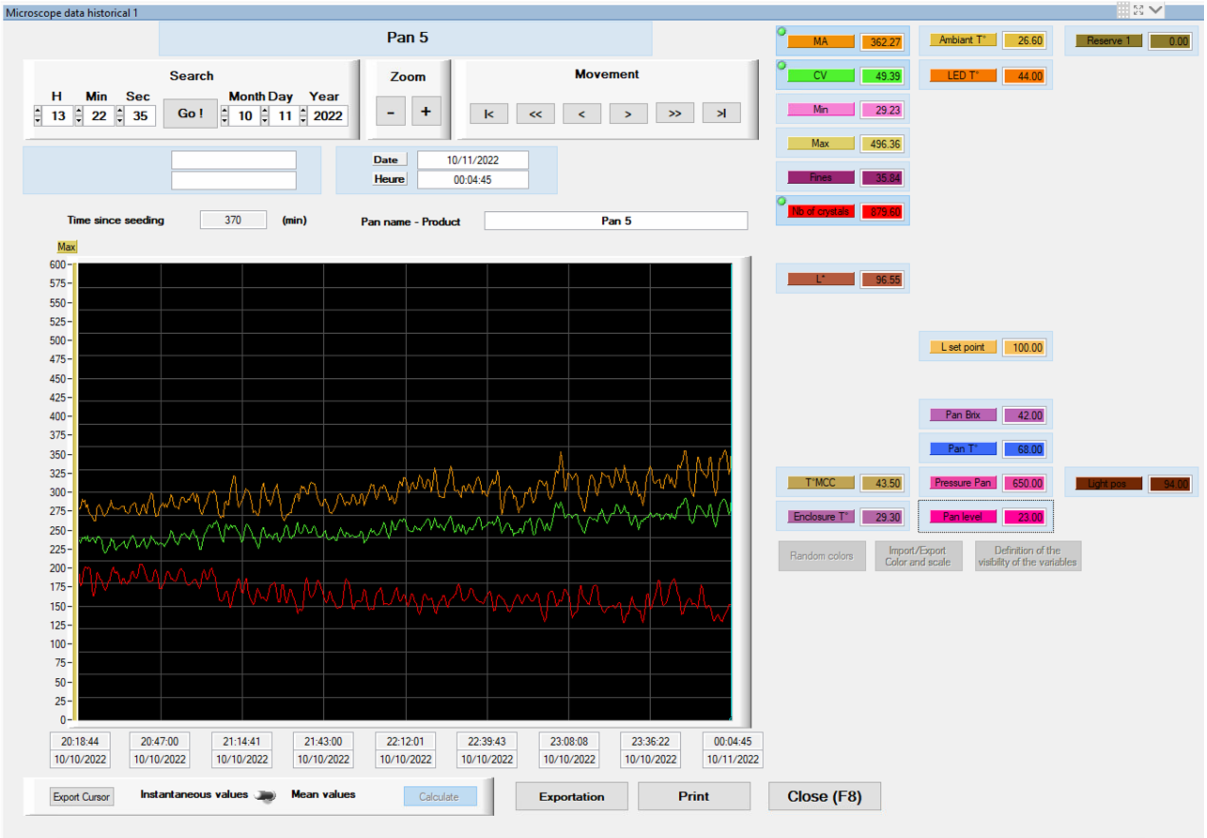


Figure A.1 Screenshot from the historical trend in the Crystobserver software.

Vacuum pan historical:

In this section, the user may look at a table with each strike recorded in the system and quickly compare their main results. It is worth mentioning that the content of this table may be customised according to the needs of the mill. Up to three strikes may be selected and compared more in depth either by the recorded images (Figure 7) or in plots.

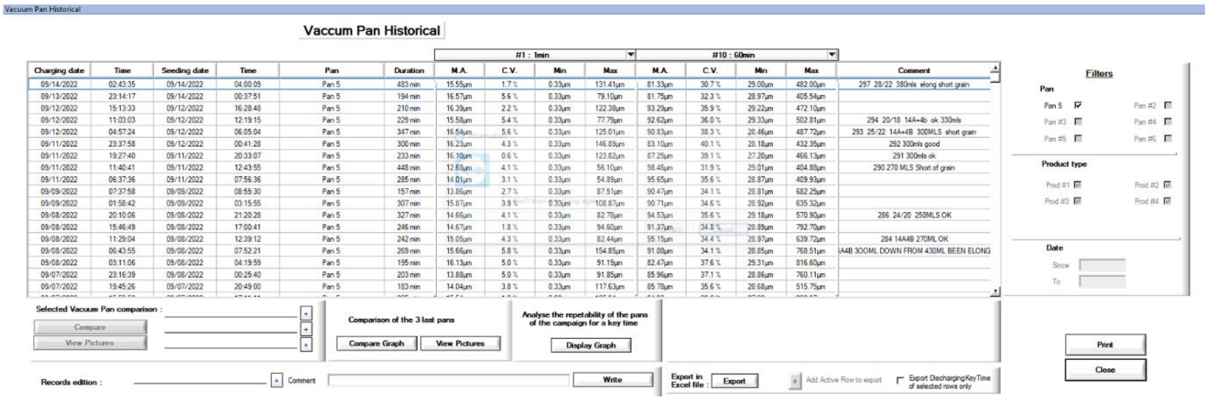


Figure A.2 Screenshot from the vacuum pan historical in the Crystobserver software.

In addition, the MA, CV and crystal number may be compared across a period of time at the same time after seeding, e.g., 30 min after seeding. This allows the evaluation of trends of crystal growth over long periods of time, e.g., more than one season. In this same analysis, a specific moment of interest may be selected and the image from that measurement analysed.

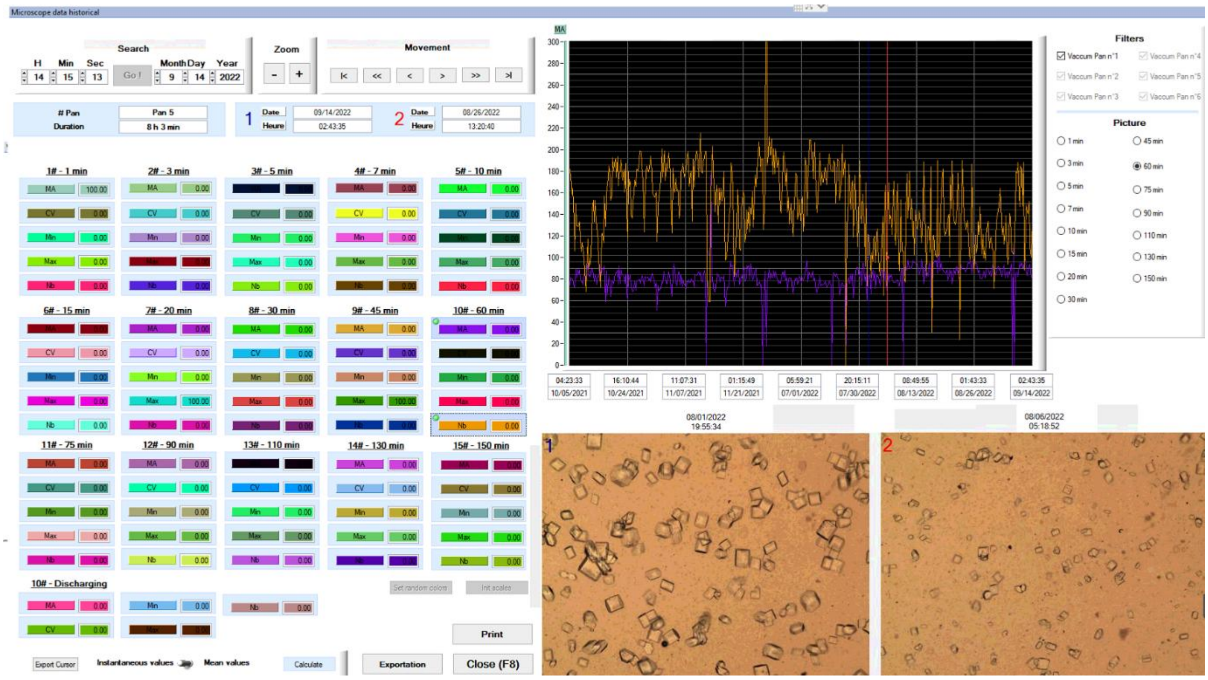


Figure A.3 Screenshot from the microscope data historical trend in the Crystobserver software.

13.2 Appendix 1 METADATA DISCLOSURE

TABLE 11. METADATA DISCLOSURE 1

Data	All files located at QUT in folder 4418
Stored Location	QUT server for CAB (Centre for Agriculture and the Bioeconomy). SRI/Projects/4418
Access	Access restricted to SRI staff in CAB
Contact	Ross Broadfoot; Gabriel Fraga

TABLE 12. METADATA DISCLOSURE 2

Data	All files located at Sunshine Sugar in folder Crystobserver
Stored Location	Sunshine Sugar server Condong\Engineering\Project Management\#PROJECTS#\Company 1 - Mill\Crystobserver Corporate\Technical Services\Projects\SRA SMRP Applications\Crystobserver
Access	Access restricted to Sunshine Sugar staff
Contact	Kent Selby; Ash Curran

14 SRA RESEARCH MISSIONS MANAGER'S RECOMMENDATION

(To be completed by the SRA Research Missions Manager, Research Investments)

Milestone Number			
Milestone Title	Final Report		
Final Report Due Date		Date submitted	
		Date of submission of revised version (if relevant)	
Date Reviewed		Date of review of revised version (if relevant)	
Reason for delay (if relevant)			
Milestone Payment			
Total Project Funding by SRA-RMS			
Project Objectives (Contracted)			
Success in achieving the objectives	☒ Completely Achieved ☐ Partially Achieved ☐ Not Achieved		

SRA Research Missions Manager's comments:

Project Outputs (brief version)

Activities to further develop, disseminate, commercialise, or exploit the Project Outputs (after discussion with CI)

Recommendation: