#1269 Practical Experience on the use of Process Analyzers in the Sugar Industry

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Abstract

Process analyzers are devices designed for the continuous or periodical in-line or off line measurement of physical or chemical parameters of an industrial process stream.

They are able to perform chemical and physical analysis and deliver in real-time measurements required for the production environment.

Besides process optimization and asset protection, process analyzers are also used for assessing compliance with environmental regulations.

The analyzers under study are:

1) **Total Organic Carbon (TOC) analyzers for waste waters: Environmental Compliance**
2) **TOC analyzers for boiler feed water: Condensate purity**
3) **Pan Microscopes: Crystallization control.**
4) **Online colour analyzers of wet sugar from centrifugals**
5) **Online moisture Sugar Moisture Analyzers: Sugar ex granulators**
6) **Silo level transmitters: Inventory control**

This report discusses the practical experiences of the various analyzers employed at sugar refineries showing the advantages and disadvantages of the various technologies.

Key words: *In-line measurement, TOC Total Organic Carbon, Sugar moisture, ICUMSA Colour, Condensate, Radar wave, Laser beam, Ultrasonic sensor.*

Introduction

I**nline, online, atline, and offline** analysis are four different methods of process analyzers, each with its own advantages and disadvantages. Depending on the application and experimental setup, process analyzers can be used in conjunction with each method to identify and characterize the chemical and physical properties of materials in different ways. The differences are described in Appendix A.

In summary, each type of analysis has its own advantages and limitations, and the choice of analysis depends on the specific application and requirements of the experiment or process. Knowing how each type of analysis works in different applications can help you determine which the best fit is. Selecting the appropriate analyzer can also play a major role in the success of the analysis.

Most people who have worked in a sugar factory or refinery have come across some instruments that are invaluable to efficient operations. Classification of these commonly used automated instruments can be roughly divided into two categories:

i) **Instruments that monitor physical parameters in the production process,** such as detecting temperature, pressure, liquid level, flow, etc.
ii) **Instruments that measure some physical or chemical property** such as the detection of turbidity, pH value, colour, oxygen content, dissolved carbon, residual chlorine, etc, and are referred to as analyzers.

Automatic inline analyzers play an important role in a modern sugar processing plants, where these instrument can continuously detect various process parameters, and carry out manual or automatic control and literally become the eyes and ears of the operators. At the same time, since the value measured by the detection instrument can be continuously compared with the set value, whenever a deviation occurs, it will be adjusted immediately to ensure the quality is met. For example in the case of a clarification process, if a deviation is measured, of the parameters detected by the instrument, it can further automatically adjust and control the dosage of lime or CO2 to ensure compliance to the set point. Since the instrument has the functions of continuous detection, it could be coupled to computer control which allows various other parameters to be monitored and controlled.

Assessment and control of water quality is essential in the sugar industry: sections 1 and 2 of this paper discuss key aspects of this (wastewater and condensate water respectively) and then in the following sections 3-6 different experiences and experiences gathered through the sugar refining process are reviewed.

1) <u>Total Organic Carbon for Waste Water: Environmental Compliance</u>

Monitoring wastewater systems is necessary to manage and mitigate the potential impacts of wastewater to the environment, aquatic life and source water quality for downstream use. For sugar refineries the three areas that are regulated are:

- Cooling water returned to lakes and rivers
- Treated wastewater to a river or a lake
- Wastewater discharged to a sewer.

When monitoring the wastewater that there are several key parameters and metrics that need to stay within your compliance limits.

Carbon parameters such as biological oxygen demand (BOD), chemical oxygen demand (COD) and total organic carbon (TOC) are common measures of the organic matter in wastewater. **Total suspended solids (TSS)** refers to matter that isn't dissolved in wastewater and that can be collected via a filter.

Total dissolved solids (TDS) TDS refers to organic and inorganic matter that does dissolve in wastewater.

Of course, here are other parameters also being measured such as pH, temperature etc. depending on local regulations.

2.1. Types of TOC Meters

The total amount of all carbon present in water is referred to as “total carbon” (TC), which can be classified into two major types, either total organic carbon (TOC) or inorganic carbon (IC).

1..1. TC: Total Carbon

TC mode measures all carbon species in a sample, both organic and inorganic. This mode does not involve acidifying the sample or purging, thus it measures the raw sample as is.

TC mode is best for conditions where the users:

- Do not need to differentiate between organic and inorganic carbon
- Do not want to pretreat samples

Only need trending information. Best applications for TC mode are:

- Condensate return
- Lake water return

TC systems utilize high temp combustion technology, and therefore a simple TC unit could be acquired that is striped off all extra elements required for TOC measurements resulting in price reduction. (Personnel communication Pavle Milutinovic, ASR Group)

1..2. TOC: Total Organic Carbon

- TOC mode is where the inorganic carbon is removed from the total carbon in a sample to determine the total organic content (TC-IC=TOC). Compared to other modes, TOC is more accurate for ppb and sub ppb level TOC mode is best for those who: Must meet compliance requirements
- Need low level sensitivity and accuracy
- Have low In Organic carbon (IC) values compared to TOC

2.1. Practical Problems with Analyzers

The accuracy of water analysis dependent on sampling method used. Continuous sampling is the best, however, it suffers frequent the blockages. The current suction tube has twenty 6mm holes. To prevent total blockage, frequent high volume back wash is required. Still requires occasional physical cleaning.

Figure 1: *Blocked sewer suction pipe, back washing in progress and a manual cleaning done*

2.1. Learnings

Previous reliability issues regarding the sample collection was addressed. The sample collection equipment is quite elaborate and robust. In this picture we can see the large peristaltic pump and the stainless steel sample overflow holding tank. This holding tank has temperature and pH sensors and piping to draw samples to the TOC meter, which can be seen at the rear. Sample pumps was at 5 cub. meter per hour into the sample collection tank and was upgraded to 10 cub. meter per hour.

Figure 2: *Sewer sampling room with peristaltic pump and sample reservoir, TOC meter in the background*

2) <u>TOC Analyzer Boiler Feed Water Protection – Condensate</u>

Total Organic Carbon (TOC) or TC Total carbon analyzers measure the total amount of carbon in organic compounds in water systems.

Condensate Purity Control

One of the main concerns of boiler operators in a sugar factory is the possibility of gross sugar contamination in any of the return process condensates destined for boiler feed. An investment in an in line analyzer to monitor the water is justified on the basis of the very high costs incurred in boiler downtime, repair and maintenance caused either directly or indirectly by sugar contamination.

Figure 3: *Picture of a boiler tube that has iron oxide deposits as a result of severe sugar contamination*

However, these high costs are incurred only when sugar contamination is excessive and undetected. For boiler safety, it is preferable to detect high levels of sugar contamination with absolute certainty than to expend great effort on the accurate measurement of small traces (Reid). A sensitive and reliable sugar trace monitoring system is essential if such a situation is to be avoided. A sugar slug to the boilers would have devastating consequences to the water chemistry of the boiler water. The sugar will degrade to organic acids resulting in a pH drop, causing immediate corrosion and fouling. Such an event requires fast reaction from the operator to:

i) Divert a majority (if not all) of the return condensate to a drain to avoid introducing further contamination into the boiler.
ii) Speed up the chemical dosing pumps to help neutralize the acid and introduce more dispersants to minimize scaling.
iii) Blow down the boiler aggressively on to remove the low pH water and solids that have collected in the boiler-heating surface and in the mud drum.

There are many costs associated with contaminating a boiler with sugar:

i) Cost of lost production due to boiler shutdown
ii) Cost of lost sugar
iii) Cost of losing boiler water by blowdown
iv) Cost of new make-up water
v) Cost of boiler fuel to heat new make-up water
vi) Cost of chemical treatment of make-up water
vii) Cost of waste treatment

All these reaction methods are very inefficient ways of dealing with the issue of contamination and the best approach is to detect and isolate the contamination before it enters the boiler. There are various condensate surveillance technologies in the market:

1. Conductivity
2. Flame photometry
3. TOC Total organic carbon
4. TC Total carbon

2.1. Conductivity

Conductivity is measured with a probe and a meter. Voltage is applied between two electrodes in a probe immersed in the sample water. The drop in voltage caused by the resistance of the water is used to calculate the conductivity per centimeter. Conductivity is measured in micromhos per centimeter (µmhos/cm) or microsiemens per centimeter (µs/cm). Distilled water has a conductivity in the range of 0.5 to 3 µmhos/cm.

While conductivity system works well in raw cane sugar factories, where the low purity massecuites have a significant amount of conductivity, it is a poor choice for cane sugar refineries, because of the low ash in white massecuites. However, the conductivity method will certainly react to gross contamination of hundreds of ppm and higher, and it is these incidents which place the boilers in the greatest danger. The relationship between sucrose content and conductivity is highly variable because it depends on the nature and quantity of these salts, hence the correlation between and ppm sucrose and microsiemens per centimeter (µs/cm) is not reliable.

2.2. Flame Photometer

Flame photometers have been in use mostly in beet sugar factories where they are found to be reliable when given proper maintenance. The instrument does not detect sucrose directly but measures the concentration of potassium that are assumed always to be present with the “leaked” sugar. For this reason they are considered to be only slightly better than conductivity monitors. (Reid)

2.3. Total Organic Carbon Meter

Online TOC analyzers offer continuous monitoring of total organic carbon levels for a range of water purity levels. For return clean condensate, it allows for immediate, preventative actions when excursions are detected to offset potential sugar contamination of the boiler. TOC meters utilize a catalytic oxidation combustion technique at high temperature (the temperature raises up to 720 ºC), to convert organic carbon into CO_2. The CO_2 generated by oxidation is measured with a Non-dispersive Infra-Red (NDIR) sensor.

2.4. Total Carbon Analyzer

A total carbon (TC) analyzer measures both the total organic carbon (TOC) present and the total inorganic carbon (TIC), the latter representing the amount of non-organic carbon, like carbon in carbonate minerals. Subtracting the inorganic carbon from the total carbon yields TOC.

2.5. Learnings

Our experience has shown that TC works especially well because in condensate, there isn't a lot of carbonate and bicarbonate or dissolved CO_2 for that matter in the sample. TC does not require any specialty chemicals either. They generally run at high temperatures with some machines reaching 1200°C. This high temperature combustion which means catalysts are not required either. Only a dilute HCL solution is needed, which can be made up in the lab very easily. In fact, a TOC can deliver TC results by simply disabling part of the instrument's capability.

The other aspects that are problematic with TC and TOC meters, are high temperature and particulates. The former is addressed by operating a sample cooler. One would expect return water to be clean but residual burnt organics and rust particles make block up the thin tubes inside the machine. This recurring problem was solved by adding an aftermarket 0.2 micron filter, which is replaced every month

Figure 4: *An inline TOC meter monitoring a first effect falling film evaporator, note the 0.2 micron filter*

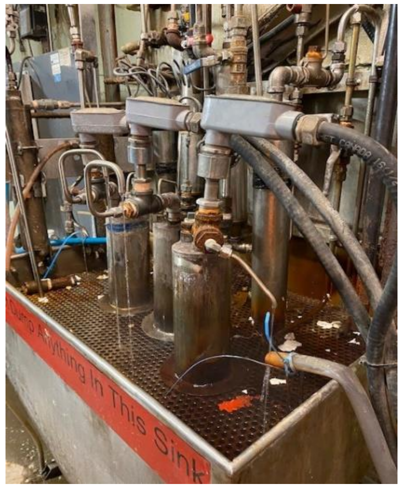


Figure 5: *A continuous sample cooler for the TOC analyzer*

3) <u>Pan microscopes</u>

Crystallization takes place in vacuum pans. The quality of the final crystal depends on the manner the crystallization conditions are managed to produce crystals free from fines and conglomerates.

There are many parameters affecting the quality of the massecuite with regards to its granulometry.

They are, syrup purity, seed size and CV, calandria steam pressure, temperature, absolute vacuum, feed solution concentration, and level of super saturation and the duration of each step.

To get a massecuite of good quality, it is essential to granulometry. In the old days of pan boiling when pan boiling was considered to be an art, the pan operator sampled the pan using a proof stick which allowed him to make a judgment of the crystal size and regularity. With automation the pan operator's skills became less relevant and pans were monitored by analogue pan cameras. These pan cameras gave a good view of the pan contents but it was still a subjective evaluation.

More recently, digital pan cameras have been developed that are able to control the pan properly and to monitor sequence of operations involving these parameters to ensure repeatable good quality massecuite strikes. This is done by real time monitoring of crystal growth, the number of crystals, the Coefficient of Variation (CV) and the Mean Aperture (MA)

The camera starts sending useful information even before seeding begins by detecting crystal in the pan liquor, either from poor pan steaming or crystals from centrifugal run-off

At the seeding stage, it counts and measures the crystals to reveal whether the desired volume with the correct size have entered the pan at the right time, the time measuring the MA and CV.

When producing large grain by cutting in magma, the pan operator will realize immediately whether he will achieve the final size. This is easy if the pan camera has software to provide CV an MA in real time.

When the pan camera is out of order, the pan operator feels like he/she is flying blind. It demands more time to monitor the pan as they have to go out to the pan and observe the massecuite on the sight glass or pull the proof stick.

While brixing up the pan to final size, it is difficult to obtain good visibility of the particle size distribution because the massecuite is dense and the crystals are fairly large when boiling coarse strikes 1mm and larger.

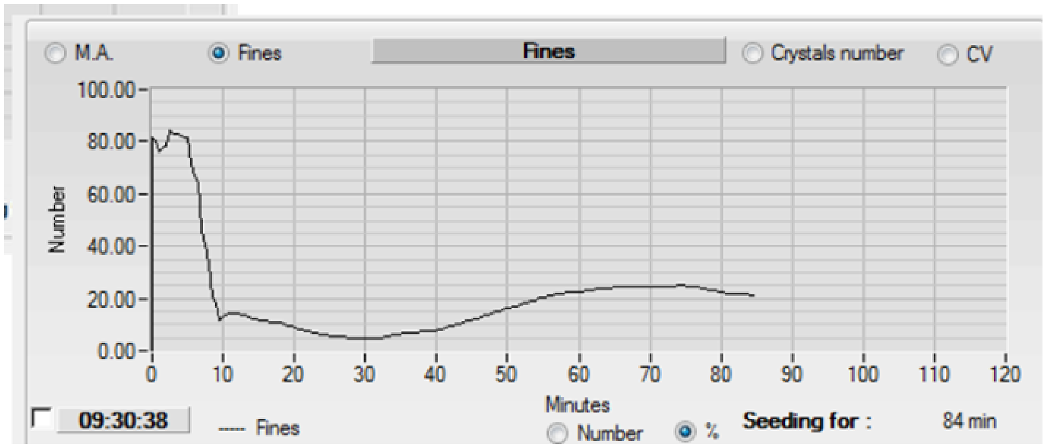


Figure 6: *False grain detection*

Figure 7: *Pan camera is fitted to a vacuum pan, above the calandria*

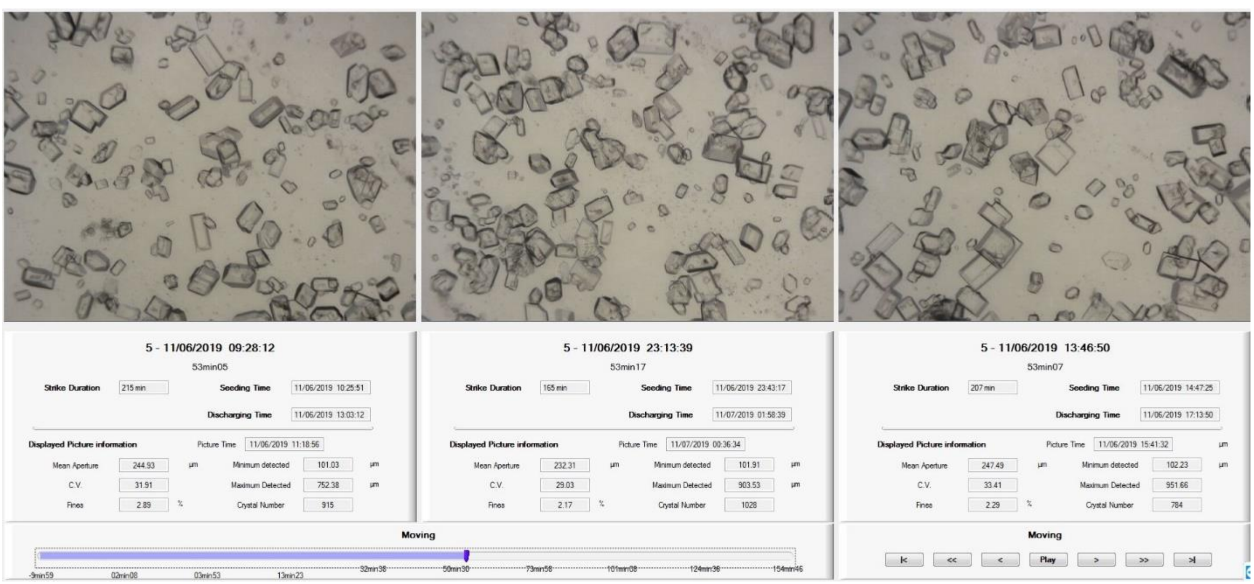


Figure 8: *Screen shot of a pan under crystal monitoring*

The above example illustrates the same pan with the same material at the same stage of the boiling. This feature allows the pan operator to visualize the strike and to identify any issues with it. The modern pan camera gives fairly good information on MA, CV and crystal number.

3.1. Learnings

Pan operators have commented on the following regarding to the pan camera:

1. Pan operators don't need to visit the pan and pull out proof sticks. They can see the crystals at all times.
2. They can visibly see the crystals entering the pan, and hence can dissolve it before seeding point. Some of these crystals could be in the liquor because of ineffective steaming of the previous strike. The operator can use the minimum amount of water to complete the dissolving process
3. If there is a problem with the automatic slurry injection, they will notice the absence of crystals after graining. This ensures "slurry success".
4. False grain detection. If false grain appears due some excursion away from the supersaturation curve, a camera with special software can detect it.

4) On line Colour Monitoring of wet sugar sugar from centrifugals

The centrifugals are practically the last step in the sugar refining process, where the operator can actually adjust the quality of refined sugar proceeding to the sugar drier and beyond. To ensure that the sugar meets the specified colour quality, operators tend towards over-washing, leading to substantial consumption of water, energy and re-dissolution of sucrose. The rule of thumb for wash water utilization in batch white centrifugals is that one liter of water can dissolve up to three kg of sucrose. It is therefore essential to avoid over washing and to use the precise amount of wash water to keep the colour as close to the specified set point.

The traditional way to implement precise washing is to take a sample off the line and take it to the lab for colour analysis. Nowadays the lab colour analysis using NIR methods takes 2 to 3 Minutes max while the original method takes 30 to 45 minutes. However, the sampling, transportation to the lab, the analysis and the time taken to report and read the results takes up to 60 min and therefore makes the data too late for correction.

A laboratory can analyse for colour every one to two hours at best, therefore leaving several discharges of centrifugals unmeasured, with possible colour variations between measurements. Without constant reliable colour analysis, there is a high risk of sending out-of specification products to the dryer or overwashing to be on the safe side. With on line colour measurement, operators can detect any fluctuation and react in real time by optimising the individual washing time of each centrifugal, thus achieving colur and washing needs.

There are several key advantages with online sugar color measurements:

- **Consistent quality:** The more measurements performed throughout a run, the more high-quality and consistent the sugar colour will be. More measurements allow for early warning and can help the operator correct changes throughout the manufacturing process as early as the clarification and crystallization processes.

- **Optimized efficiency:** In-line measurements also helps collect a large batch of sample measurements without labour intensive sampling and sample testing and saving valuable personnel time.

- **Customer complaints:** With in-line color measurement, a refiner can increase the color quality and earn a reputation for quality excellence.

4.1. Refinery Reliability

One of the benefits of this equipment is the detection of unspun massecuite going to the drier/granulator, which would clog up the louvres or flights, which could result in stopping the line whilst the drier/granulator is cleaned.

Now we can review three different experiences of the use of centrifugal colour analysers, two for wet sugar and another for dry sugar .

- **Refinery U:** In this refinery the online sugar colour transmitters are located in two distint areas, namely wet sugar from one of their three routes and dry sugar at the silo inlet. Both systems are located over rubber belt conveyors. The wet sugar route is monitored by the operator who manually adjusts the wash water timing. The transmitter on the dry sugar route to silo is used to ensure that the sugar fed to the silo is always within specification by high and low colour alarms.
- **Refinery S:** In this refinery the online sugar colour transmitters is located above a grass hopper, supplied by six BMA1250 centrifugals. The plant has a back-boiling system which necessitates careful monitoring sugar colour to remain within spec.
- **Refinery A:** In this refinery the online sugar colour transmitters are located over rubber belt conveyors monitoring wet sugar from all white centrifugals. The wet sugar route is monitored by the operator who manually adjusts the wash water timing.

Figure 9: *Empty conveyor detector, a sensor that detects the absence of sugar*

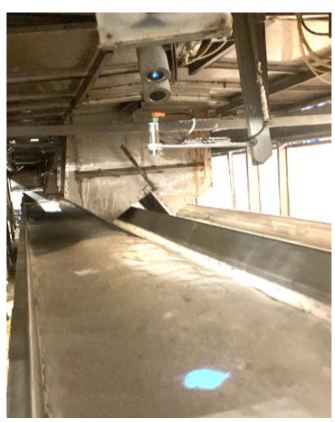


Figure 10: *the blue light indicates the direction of the colour transmitter*

Figure 11: *A colour monitor located above the wet sugar belt ex centrifugals*

4.2. Learnings

One of the issues experienced is drift in the colour from cameras in humid areas, which was caused by droplets of water condensing on the lenses. Some refineries addressed this by improving air circulation or by introducing a heat source in the vicinity.The cameras installed above dry sugar conveyors need regular lens cleaning due to dust build up.

The design of system has to “see” empty conveyors to provide correct measurements of sugar only.

The ability to see sugar colour on line has a direct benefit total wash water usage to the white centrifuges. Operators do not need a higher wash to be on the safe side thus helping to maintain a higher centrifugal yield.

Refineries which installed sugar colour monitors had a significant improvement in silo colour control thus reducing customer complants.

Early warning of white centrifugal sprays misalignment or blockages which causes extra washing to achieve average sugar colour.

4.3. Conclusion

Reduction in wash water usage on the white centrifuges.

Improvement of centrifugal yield

Improvement of sugar quality with regards to colour

Reduction of recycle and material sent to the recovery/remelt side

5) On line Moisture Analyzer: Sugar ex granulators

During sugar processing, the drying of crystalized sugar is the most important step after the centrifugal separation to guarantee a high quality of finished product. Sugar drying removes excess moisture from the sugar using heat and air. Without processing the sugar in this way, clumping and discoloration during storage would occur, degrading the quality and value of the final product.

Sugar from the centrifugals contains about 0.5% - 1.0 % moisture. If this moisture is not removed, the sugar will form hard lumps in silos and bags. The final dried sugar moisture range between 0.02 % - 0.04%. This is analyzed in the laboratory by the loss on drying method or by bench top NIR instruments.

Normal moisture analysis takes up to 4 hours by loss of drying at 105 C° for 3 hours then inside a desiccator for another 30 to 60 min. The NIR laboratory moisture analyzer measures the moisture in 5 min. If we add sampling, sample delivery, analysis and reporting, the time is best at 60 minutes

In the sugar industry, several types of drier/granulators in service:

- Rotary Cascade or Louvre
- Fluidized Bed

All of these units drying capacity is dependent on the flow of material and drying air. Any disturbance to this will result in poor drying performance. This is where the use of continuous moisture analysis becomes useful for process control. The main benefit of on-line moisture meters comes from eliminating the possibility of out of spec product occurring between lab samples.

It is possible for a moisture analyzer to control the drier/granulator operation by adjusting the temperature and volume of air flow. So far we have not come across any sugar factory at this stage of implementation. The moisture analyzer at Redpath is used for drying performance indication and serves all four drier/granulators. If the moisture rises above 0.3 for 10 seconds, it will stop the line.

The moisture analyzer at Redpath is on line as samples are extracted, measured and dumped back onto the line with a blast of compressed air.

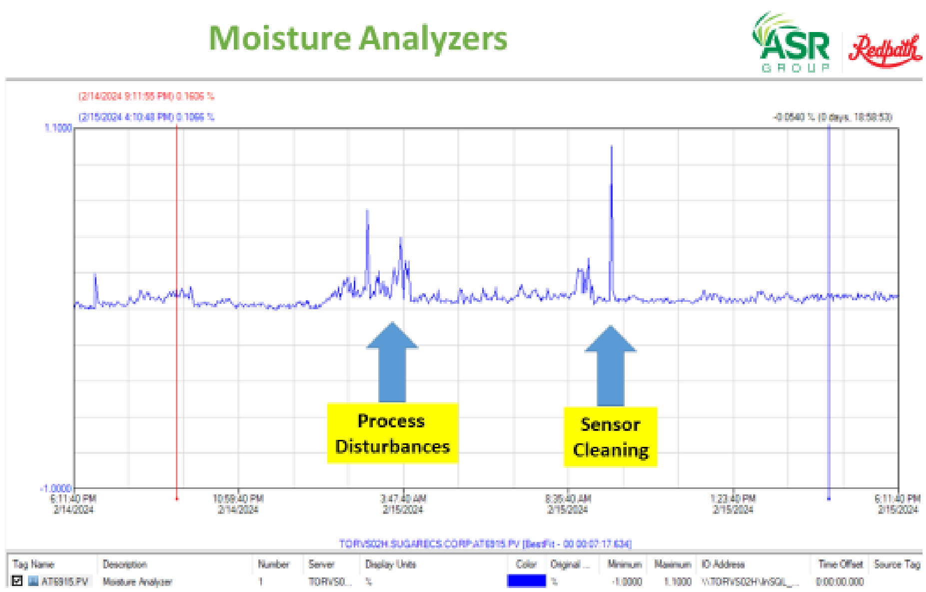
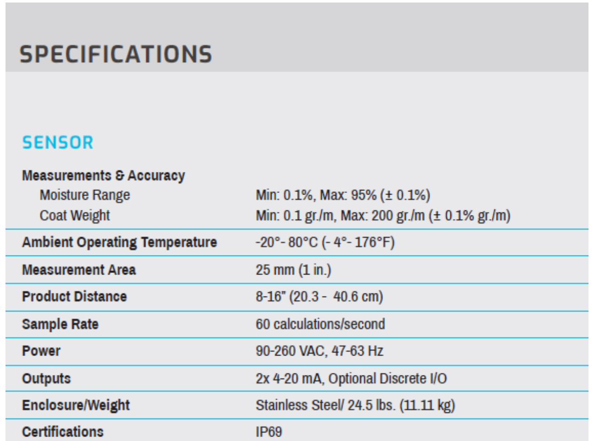


***Figure 12**: Average moisture trended over 24 hours*

Figure 13: *The moisture analyzer panel located near the driers/granulators*


Figure 14: *Moisture analyzer in position*


Figure 15*:* *Moisture analyzer retracted for cleaning*



SPECIFICATIONS

SENSOR

Measurements & Accuracy	
Moisture Range	Min: 0.1%, Max: 95% (± 0.1%)
Coat Weight	Min: 0.1 gr./m, Max: 200 gr./m (± 0.1% gr./m)
Ambient Operating Temperature	-20°- 80°C (- 4°- 176°F)
Measurement Area	25 mm (1 in.)
Product Distance	8-16" (20.3 - 40.6 cm)
Sample Rate	60 calculations/second
Power	90-260 VAC, 47-63 Hz
Outputs	2x 4-20 mA, Optional Discrete I/O
Enclosure/Weight	Stainless Steel/ 24.5 lbs. (11.11 kg)
Certifications	IP69

Figure 16: *Moisture analyzer specification from vendor 1*

Measured NIR Constituents: 2 simultaneously
Moisture Range: Min. 0.1%, Max. 95%
Fats & Oils: Min. 0.1%, Max. 50%
Product Distance: 8-18 inches (200-450mm)
Calibration Codes: 100
Response Time: 1 – 999 seconds. Three modes available: damping, integration and gated.
Power: 90-260VAC, 50/60 Hz, 40 watts
Outputs: 4-20mA, 0-10V (isolated), RS-232 & RS485
Weight/Enclosure: 17 lbs. (8.6kg) / 316 Stainless Steel
Operating Temperature: 0-60 °C, up to 80°C with cooling
Window Purge: Air Purge Diffuser

Figure 17: *Moisture analyzer specification from vendor 2*

5.1. Learnings

The sensitivity of this machine was known at the time of purchase, and while it didn't have the guarantee of measuring at the ideal range 0.01% – 0.05% moisture, it was installed for two reasons

1. Real time monitoring of any moisture related disturbances
2. Reduce the manual work for hand sampling sugar by granulator operators

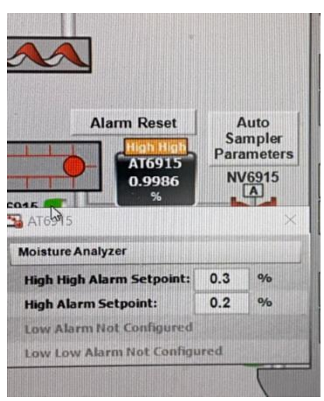


Figure 18: *Here is the HMI display.*

It can be seen that the moisture has reached 0.9986 %. This is a High High situation

As per the logic, if it is greater for 10 sec more than 0.3% it will interlock the drag conveyor DC6915, which is exactly what has happened in this situation. This is the way very wet sugar is prevented from reaching the silos.

6) <u>Silo level measurement</u>

The purpose of measuring the silo level is to monitor sugar inventory and ensure that the silos are not overfilled. An automatic system is more accurate than a manual system, and silo data is always available independent of weather conditions or time of day. This eliminates the need for human intervention and manual-dipping, thereby reducing operator risks and product contamination.

All of the transmitters mentioned in this report except 3D laser only measure a single sample point across the entire undulating surface of the stored material. Readings will therefore differ depending on where the instrument is located on top of the silo. This is true for 'silo dip testing' as well.

Unreliable stock level reports cause a tendency to hold higher levels of safety stock to avoid shortages that would halt production. Ultimately this leads to higher than necessary production costs and reduced profitability due to the cost of the excess stock, but worse, an incorrect silo level could cause overfill, leading to mechanical damage and in some cases fire.

The following methods are available for level measurement:

- Silo dip
- Ultrasonic
- Laser
- Radar

6.1. Silo Dip

This requires a measuring stick, rope or measuring tape. All of these require an operator to implement.

- **Advantage:** Cheap and low tech
- **Disadvantage:** Requires contact with product and possibility of contamination as the silo top access cover is opened.

6.2. Ultrasonic

Ultrasonic silo level measurement is based on ultrasonic sensors that mimic what bats do. They use piezo crystals to generate a mechanical pulse, usually between 23 kHz and 40 kHz, and direct this towards the target surface. They then time how long the signal takes to return. Ultrasonic technology is not popular in refined sugar silos because of sugar dust in the measurement zone.

- **Advantages:** Non contacting. Ultrasonic sensors tend to be accurate to within one per cent, which is acceptable for most industrial and manufacturing users. As ultrasonic silo level sensors contain no rare materials, they tend to be relatively inexpensive. This is particularly useful if used in industrial processes where damage might occur. They are resistant to electronic and acoustic noise meaning they can be used in a large range of environments without the risk of false readings.
- **Disadvantages:** Not available in 3D, therefore multiple transmitters are required for a wide silo in excess of 3 meters. Because ultrasonic sensors work by emitting sound which then bounces off a target surface, it can be affected by thick dust. Instead of reaching the target surface, the

soundwaves bounce off the dust particles and give a false reading as to how much material is in the silo. Dirt or condensation on the sensor can also mean they return inaccurate readings, so sensors must be cleaned on a regular basis.

6.3. Laser

This works by mounting a laser transmitter and receiver at the top of the silo. The transmitter produces a set high-frequency electromagnetic wave which rebounds off the product surface and is detected by a sensor to produce a reading of how much material remains in the silo.

- **Advantages:** Non-contacting. The laser beam is narrow, being only a few centimeters in diameter even at more than 30 m, it does not interfere with the vessel side or other obstructions.

- **Disadvantages:** Laser only measure a single sample point across the entire undulating surface of the stored material. Readings will therefore differ depending on where the instrument is located on top of the silo. Dust affects the signal and makes it unreliable for this use in refined sugar, but satisfactory for raw sugar.

6.4. Radar

In radar level measurement, radar waves are transmitted to the measured product, reflected by the product surface, and received back by the antenna system. The time from emission to reception of the signals is proportional to the level in the vessel. There are two types, a single beam which are suitable for narrow silos and 3D systems which are best or large diameter silos. These 3D radars can measure the undulating surface of the product to provide an accurate volume of the solo.

- **Advantage:** Non-contact. Impervious to dust or temperature fluctuations. They are very accurate.

6.5. Case Studies

6.5.1. Refinery D

This refinery has the following silos

Content	Capacity MT	Number	Height m	Diameter m	Sensor Type
Raw sugar	1,000,000	1	80	220	Laser
Raw sugar	150,000	3	77	58	Laser
Refined sugar	52,000	2	52	40	Radar
Refined sugar	17,000	2	38	28	Radar

Refinery D has both radar and laser transmitters and these have been in service since 1995 and 2006 respectively. While laser and radar have excellent level measurement capabilities, they are employed for different products. Laser is used for raw sugar while radar is used for refined sugar.

The reason why laser is not used in white sugar silos, is due to interference of the signal by sugar dust.

Refinery D uses single point radar and lasers, and in order to overcome the undulating surface area of the silo contents, they use multiple sensors. The same system is used for the three 57 m diameter silos.

For the two 28 m diameter silos, each have three single beam radar level transmitters

For the two 40 m diameter silos, each have five single beam radar level transmitters

6.5.2. Refinery J

This refinery has the following silos:

Content	Capacity MT	Number	Height m	Diameter m	Sensor Type
Refined sugar	8,000	2	52	40	3D Radar
Refined sugar	800	2	19	8	Radar

Refinery J has single beam and 3D radars for their four silos. The narrower 8m silo has a single beam radar transmitter while the larger 40 m diameter silo has three 3D units covering the full face of the surface topography. During financial inventory measurement, they use a third party who measures using a portable laser device, in dust free conditions. (Personal communication N Tharwat and M Abdelnaby)

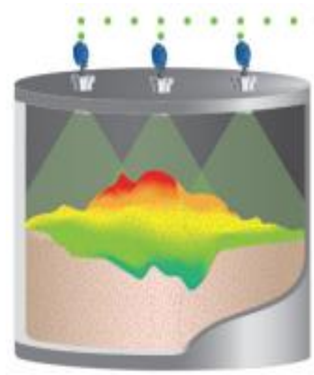


Figure 18: *A silo with a 3D scanner*

6.5.3. Refinery R

This refinery has the following silos:

Content	**Capacity MT**	**Number**	**Height m**	**Diameter m**	**Sensor Type**
Refined sugar	4000	2	35	13	Radar

Refinery R has single beam and 3D radars for their two silos. The accuracy of this is not satisfactory and weekly silo dips are conducted to confirm the true silo level. The single beam radar is located near the silo wall while the silo dip access is centralized.

6.5.4. Refinery B

This refinery has the following silos:

Content	**Capacity MT**	**Number**	**Height m**	**9.7**	**Sensor Type**
Refined sugar	1600	4	27	10.5	Radar

Refinery B has two single beam radars for each of their four silos. Having two radars per silo provides much needed redundancy. The transmitters are mounted off center, 180 degrees from each other, so they point in at about a 6.5-degree angle to reach the lowest point of the cone.

They both never read the same thing (typically within 2% of each other) and sometimes one will lag behind the other. (Personal communication James Harlow ASR group)

Some of the commissioning issues experienced with these transmitters were:

- getting them pointed in the correct direction (Vendor came in to help)
- eliminating the electronic noise that they were encountering (Vendor support)

Figure 19: *2D Radar*

Figure 20: *3D Radar*

6.6. Learnings

Radar systems are best for refined sugar silos.

The single point radar system is suitable for narrow diameter silos, however, in wider diameter silos, the undulating surface area of the silo contents makes the single point system inaccurate. Thus a 3D radar system is best for accuracy and reliability.

Having more than one sensor is an advantage from a redundancy point of view.

Final Conclusions

Process analyzers are designed for the continuous or periodical in-line or off line measurement of physical or chemical parameters of industrial processes. They have proven to be invaluable in today's fast paced low manpower operations. They deliver results in real-time measurements which allows operators to make quick corrections or automation to manage the control

The following analyzers were examined:

1) **Total Organic Carbon (TOC) analyzers for waste waters: Environmental Compliance**
2) **TOC analyzers for boiler feed water control: condensate**
3) **Pan Microscopes**
4) **On line colour analyzers of wet sugar from centrifugals**
5) **On line moisture Sugar Moisture Analyzers: sugar ex granulators**
6) **Silo level transmitters**

In general, it can be said that these analyzers, while not perfect, are fulfilling important surveillance activities in the process, utilities and environmental domain.

As technology progresses and the use of artificial intelligence becomes more common place, these analyzers will be the eyes and ears of the sugar operations.

Appendix A

Inline : Here the analyser is integrated directly into the manufacturing or processing line, allowing for real-time monitoring and control of the process. This approach involves continuously monitoring the signal during a chemical reaction or manufacturing process. The probe is integrated into the process stream, allowing real-time monitoring and control of the reaction. Real-time monitoring allows for immediate corrective action to be taken, reducing waste and improving product quality. This approach is useful for studying the kinetics of a reaction or optimizing the reaction conditions.

On line: Online analyzers are similar to inline analysis, but it is typically performed in a separate area adjacent to the production line. The samples are transferred from the production line to the analyser via tubes or other conveying devices. This approach involves periodically sampling the reaction mixture and analyzing it. The sampling is done automatically, and the analysis can be performed in a matter of minutes. This approach is useful for quality control and batch-to-batch consistency in manufacturing processes.

At line: At line analysis allows for more simple analysis than online or inline analysis, but the results are not immediately available. In this type of analysis, samples are taken from the process stream manually and brought to a benchtop or hand held analyzer. This approach provides more detailed information about the reaction products and is best used when samples are extracted from various parts of the plant. At line analyzers can be used to analyze samples from a production process, to measure the pH, brix or conductivity of a sample. It's often used for quality control in the food and beverage industry.

Off line: Offline analysis is similar to at line analysis, but it is performed in a laboratory setting. A key difference is that offline analysis is sometimes performed hours or even days after the sample was collected. This approach is useful for forensic analysis or for studying samples that cannot be easily analyzed in real time. This type of analysis is the most accurate and precise, but it is also the most time-consuming and costly.

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