VAISALA

The advantages of liquid concentration measurement over density measurement

eBook for sugar refineries

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Contents

Introduction

In this eBook, we analyze the benefits and limitations of density and liquid concentration measurements as tools for process control in the sugar refining industry. A comparative table on the features of the commonly used density technologies and refractive index (RI) technology for liquid concentration measurement is provided from the point of view of measured process medium, process operation, and instrument attributes.

Next, we review the beet and cane sugar production process and identify critical parameters for ensuring ideal sugar crystals. Finally, we provide an example of an optimized sugar crystallization process from a sugar refinery and describe in detail the supersaturation-based control solution that enabled a substantial profitability boost for the refinery.

This eBook is for instrumentation specialists, technology managers, and process and automation engineers working in the sugar refining industry. The insights in this eBook can provide valuable information for both greenfield sugar mills and existing sugar plants that aim at modernizing their production process with easy-to-implement process control solutions.

Contact us


Liquid concentration or density measurement
for efficient and sustainable processing

In industrial applications, whenever liquid material flows through pipelines it must be measured. During processing the liquid composition and concentration change, and measurements of these changes can be used as a key parameter for data-based decision making about process adjustments.

Industrial producers rely on continuous inline liquid concentration or density measurement for process control. The objective of process control is to keep key process operating parameters within the carefully defined bounds of the reference value or setpoint and thus maintain operational efficiency and ensure that the end products have the desired properties. Remote process control and diagnostics help to streamline production by optimizing the use of raw materials, eliminating waste, and reducing energy consumption as there is no need to re-process the slurry in case of quality deviations.

In this section we review the theory and operation principles behind inline concentration measurement of both refractive index-based measurement technology and density-based measurement technology.

Later in the eBook we present the most important aspects to consider when choosing a suitable measurement solution for various processes. We also illustrate the advantages of inline liquid concentration measurement over density meters for sugar refining.

What is concentration and what is density?

Refractive index and density are fundamental physical properties that can be used to indicate the amount of a substance contained in a liquid – and therefore the liquid concentration. The core difference between concentration and density is that concentration describes how much of a substance is dissolved in a mixture (dissolved solids) while density describes the mass of a material per unit volume.
For example, seawater salt concentration is approximately 35 g/l (a liter of seawater contains 35 grams of dissolved salt), resulting in a density of approximately 1.03 kg/l (a liter of seawater weighs 1.03 kilograms).

Changing the concentration of a solution changes the density and refractive index of the solution – refractometers and density meters use this relationship to measure liquid concentration.


Liquid concentration measurement for industrial
process control – general aspects to consider

When choosing the right analytical instrumentation to ensure product quality, process safety, and overall control, it is essential to evaluate both CAPEX and overall cost of ownership, including engineering, installation, calibration, and maintenance costs.

Additional practical aspects to gauge are process conditions that can have an impact on the performance and measurement accuracy of such things as impurities, entrained gas, pressure, temperature, and flow.

Accuracy and repeatability

How accurate does the instrument need to be? Does the measurement uncertainty need to be traceable, or is excellent repeatability more important for the intended application? In many cases, inline instruments can be field adjusted against laboratory reference sample measurements, and thus the fact that the inline measurement is repeatable and consistent is more important than standalone accuracy.

Learn more from our accuracy statement.

Long-term stability

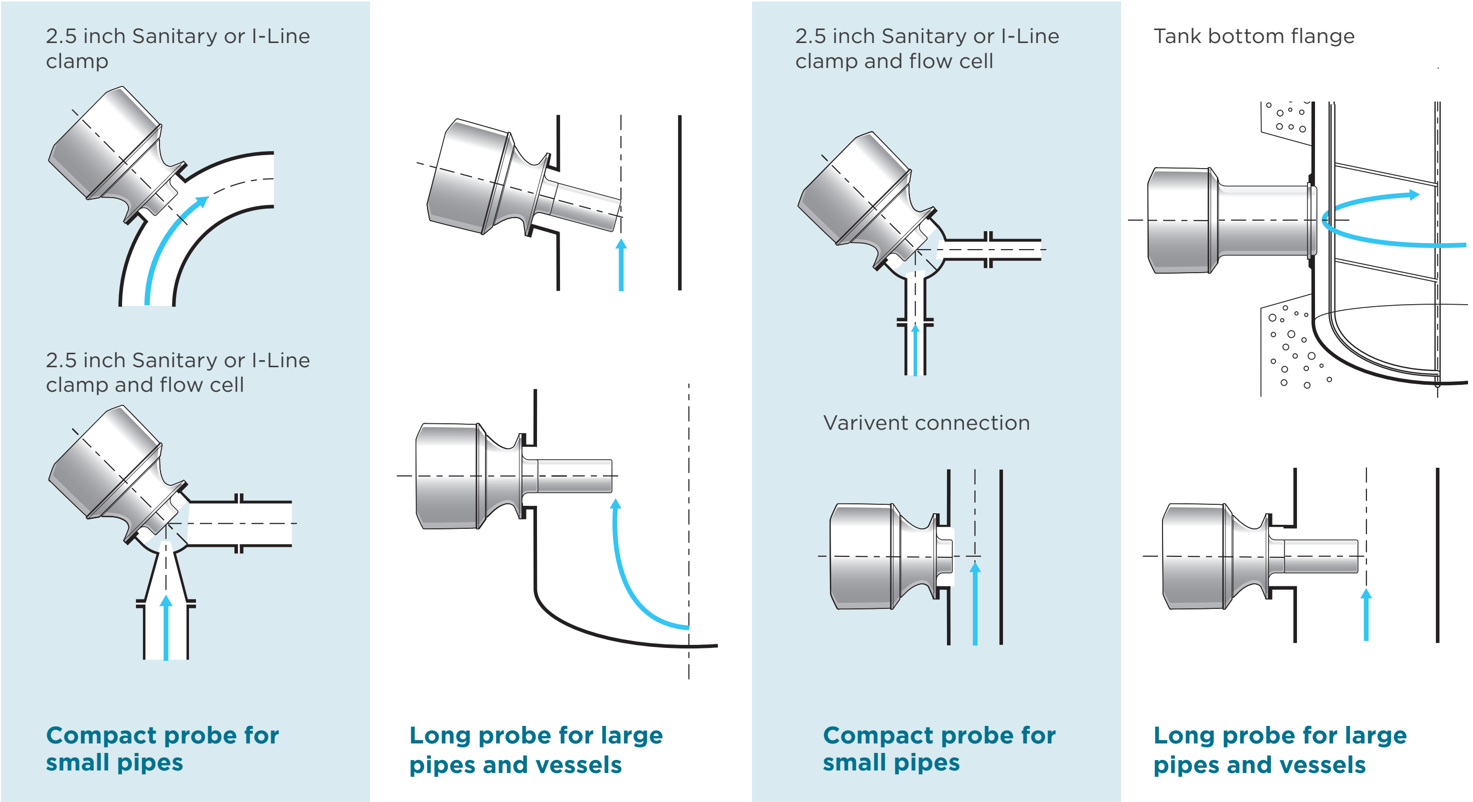
How much measurement drift can be tolerated? How often does the sensor need to be recalibrated or maintained – something that results in costs and a measurement outage? An instrument that is robust and maintains its promised accuracy may be better than one that has superior accuracy specification but does not provide reliable readings after a certain period of time. Also note that the stability of measurement accuracy can be affected by both internal measurement drift mechanisms and external error sources. For example, corrosion and wear can cause drift in some measurement techniques.

Installation options

Is the intention to measure from a pipe or a tank? Is the instrument designed to be installed directly in the main line, or can it be installed on a side stream? Some instruments and measurement techniques are strictly limited to pipeline installations – or even specific pipe orientations or diameters – whereas others offer more flexible options for installation, or even the possibility to retract the instrument from the pipeline without having to interrupt the process.

Cost of ownership and return on investment

Although a more accurate and stable measurement instrument may often cost more up front, it is important to consider the total cost of ownership including recalibration and maintenance costs. Moreover, in many industrial measurement applications a better measurement can provide more savings by reducing raw material or energy use, eliminating product loss, or increasing throughput or yield.



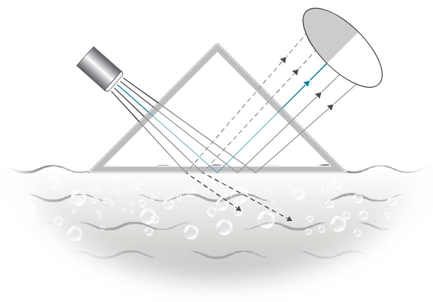
Installation options for the Vaisala Polaris process refractometer.


What is a process refractometer?

A process refractometer is based on the principle of refractive index measurement, which is a highly accurate measurement of the dissolved components in a liquid. Inline measurement with a refractometer eliminates the risk of solution contamination associated with manual sampling.

The measurement principle behind a refractometer is critical angle measurement. There are three main components in a refractometer: a light source, a prism, and an image detector. The light source sends light rays at different angles to the prism and process interface. Rays with a steep angle are partly reflected into the image detector and partly refracted by the process. Rays with a low angle are completely reflected into the detector. The angle from which total reflection starts is called the critical angle.

The image detector detects a bright field and a dark field corresponding to partially reflected light and fully reflected light. The position of the borderline between the bright and the dark areas correlates with the critical angle, which is a function of the refractive index – and therefore correlates with the concentration of the solution.



A built-in temperature sensor measures the temperature (T) on the interface of the process liquid. The sensor converts the refractive index (nD) and temperature into concentration units.

The Vaisala Polaris process refractometer can indicate different scales, for example Brix, liquid density, and concentration by weight. The diagnostics program ensures that the measurement is reliable. Because the measurement is based on critical angle measurement it is not influenced by crystals, particles, bubbles, or the color of the liquid, making it an ideal solution for sugar manufacturing needs.

Vaisala Polaris PR53GP probe process refractometer

A look inside the inline Polaris process refractometer

The inline Polaris PR53GP is a general-purpose probe refractometer for measuring concentrations of various solutions, for example sugars/Brix in a medium. It can be installed directly in a pipeline or tank and is suitable for production and quality-control applications in the sugar industry.

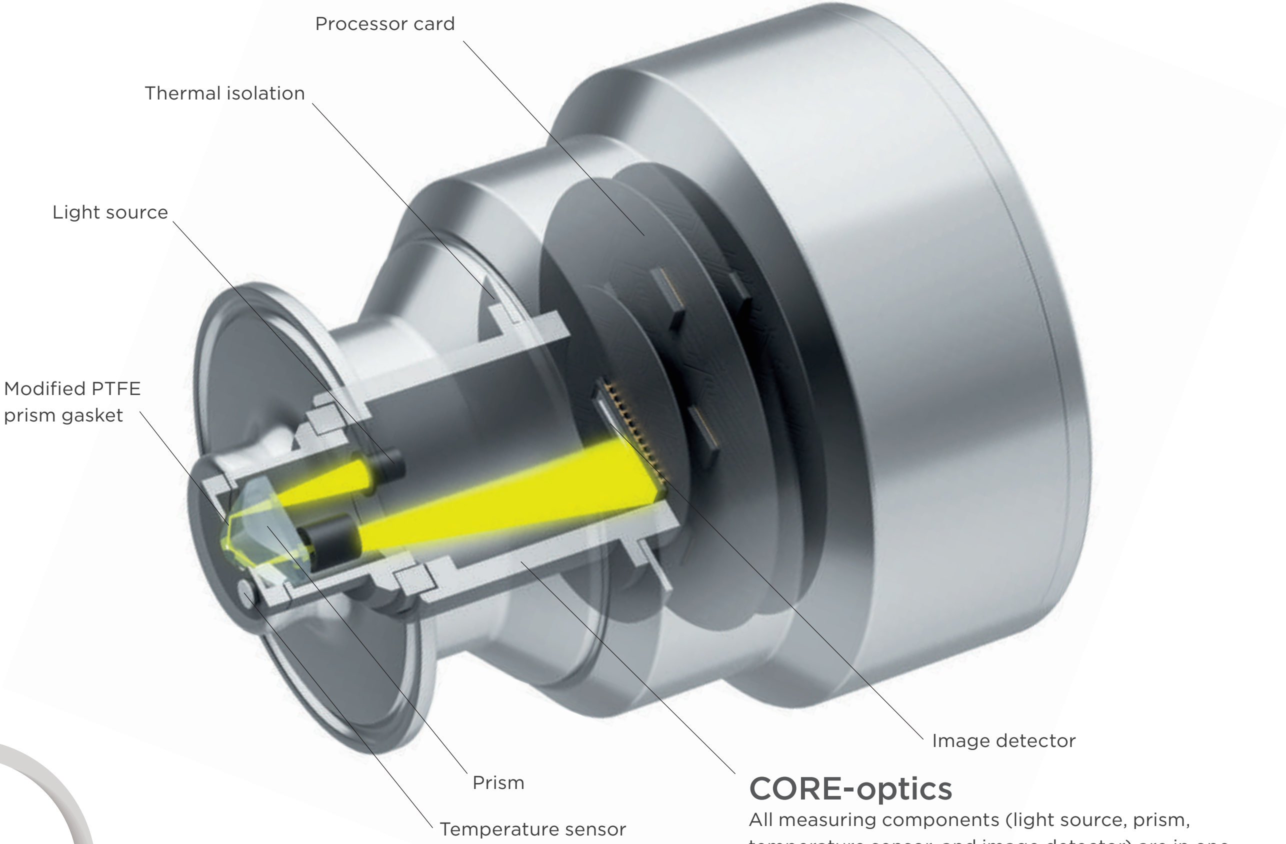
Outstanding long-term stability provides years of accurate, continuous, fast, and stable concentration measurement directly in the process stream. Inline process refractometers are easy to install and have no moving parts that require regular maintenance.

The Vaisala Polaris PR53GP includes the CORE-optics module, a rigid unit that consists of the main measuring components: the light source, prism, temperature sensor, and image detector. Because the module is mechanically isolated from external forces, measurement is not disturbed by vibrations.

The PR53GP continues the success of the Vaisala K-PATENTS process refractometer series. Based on 40 years of experience and continuous development, the PR53 family is the latest generation of digital process refractometers.

Read more about the PR53GP

Vaisala Polaris process refractometer design



CORE-optics

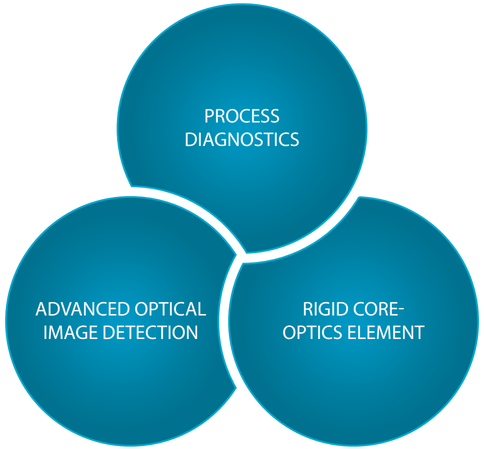
All measuring components (light source, prism, temperature sensor, and image detector) are in one solid CORE-optics module.

The CORE-optics module is mechanically isolated from the influence of external forces and vibrations. The CORE-optics require no mechanical adjustments.

An optical window into the process

Once installed, the Vaisala Polaris process refractometer provides remote access and an overview of the process. When paired with a Vaisala Indigo520 transmitter, it provides access to features such as data storage, a graphical interface, and an analog and digital interface. The Indigo520 transmitter is required when the application or the installation position requires washing to control the process. Changing settings, measurement parameters, or other servicing updates can be done directly from the Indigo520 or through a USB cable using Vaisala software.

The diagnostics display on the Indigo520 transmitter shows the optical image graph. Together with the raw measurement data and diagnostic values, these provide a clear picture of the process. For instance, the display shows when the process pipe is empty. This function allows for easy remote process diagnostics.



Distinctive features of the Vaisala Polaris process refractometer

What is a density meter?

Density meters can determine liquid density through different measurement techniques such as Coriolis, ultrasonic, microwave, or nuclear. Each of these has various strengths and weaknesses.

Coriolis meters

Inline Coriolis meters measure mass flow. The instrument has internal oscillating tubes, configured for example in a U-shape. The tubes cause the liquid flowing through them to create a twisting force due to the Coriolis effect. This force is measured by extremely sensitive sensors in the tubes, and the result is used to calculate the mass flow rate, and optionally, the liquid density.

The tubes can be coated with a protective layer to increase tolerance to corrosive chemicals. An advantage of Coriolis meters is that multiple parameters can be measured by a single instrument, including mass flow rate and density and volume flow.

One of the disadvantages of a Coriolis meter is that it is an indirect measurement of liquid concentration. The density reading is impacted by slurries and bubbles, and the instrument is calibrated for concentration typically only at a nominal temperature.

Another disadvantage is that the force sensors in the instrument are prone to vibrations from external sources such as pumps. The process liquid can coat, clog, or corrode the tube wall, affecting the resonating properties and causing measurement error. Wear of the moving tubes and possible protective coatings also cause drift in the measurement, and the protective coating does not tolerate low pressures. Moreover, the instrument cost for large pipe diameters and double or triple U-tube configurations is relatively expensive.

Ultrasonic meters

Ultrasonic meters measure the propagation of sound waves in liquid. As the liquid density affects the sound velocity, an ultrasonic meter can be calibrated to indicate the liquid density. The measurement probe can be configured as a metallic fork type and can be coated with a protective layer to increase tolerance to corrosive chemicals.

The denser the liquid, the more the sound waves moving through it attenuate. Therefore, ultrasonic density meters work best at specific ranges, typically in liquids with low density or low dissolved solids content.

While ultrasonic meters are relatively inexpensive and can be installed vertically or horizontally, bubbles and suspended particles attenuate the meter’s ultrasonic waves, creating noise and reducing measurement accuracy. Furthermore, the technique is not optimal for high concentrations. Corrosive chemicals or abrasive particles in the process liquid can coat or corrode the probe, causing measurement error.

Microwave density meters

Microwave density meters measure the propagation velocity of microwaves in the process medium. The dielectric constant of the liquid determines the propagation velocity. Because the dielectric constant of solids (dissolved or suspended) is significantly different from that of water, the velocity can be used to calculate the liquid density.

While microwave density meters can work well in applications with challenging high-turbidity and high total solids liquids, the equipment is relatively expensive, measurement is disturbed by slurries and bubbles, and as a liquid concentration measurement technique this method has limited sensitivity and accuracy for low concentrations and small changes. Additionally, pipe coatings can cause measurement drift.

Nuclear density meters

As with microwave density meters, nuclear density meters utilize the propagation velocity of radiation in the process medium to determine the liquid density. A significant advantage of nuclear density meters is that they can measure without having to penetrate the pipe. However, nuclear equipment is potentially hazardous and thus operating it requires strict safety protocols. Monitoring and disposing of the equipment according to these protocols can be very complex and costly, and the degradation of its nuclear radiation source reduces the instrument’s accuracy over time.

Comparison of concentration and density measurement technologies

Density and refractive index are physical parameters used to measure liquid concentration and composition. Density meters can be affected by air bubbles, particles, impurities, deposits, solids, changes in flow, and turbulence. Temperature changes also affect density meters as they need to achieve thermal equilibrium before the measurement is accurate again.

A density meter measurement is based on the assumption that the volume in the pipe is the same at all times.

In contrast, measurements based on refractive index – such as with the Vaisala Polaris process refractometer – avoid these drawbacks. Air bubbles, particles, impurities, deposits, solids, changes in the flow, and turbulence have no impact on the accuracy of measurement. Likewise, comparative analysis of RI-based measuring devices with regard to long-term stability, recalibration, and verification all indicate as-good or better efficiency and performance compared to density meters (see performance analysis table on the next page).

Features	**Refractive Index by** Vaisala in-line process refractometer	Density			
		Coriolis	**Microwave**	**Ultrasonic**	**Nuclear**
Process medium					
Gas (bubbles) or suspended solids (particles) in liquid	No effect, selective measurement of liquid phase.	Affect twisting Coriolis force of the solution and therefore impacts density reading.	Affect microwave propagation and therefore impacts density reading.	Affect ultrasonic propagation and therefore impacts density reading.	Affect nuclear radiation propagation and therefore impacts density reading.
Pipe deposits	No effect, high flow velocity provides self-clean effect. Prism wash options available for harsh environments.	Affect the resonance frequency and therefore cause drift. May be plugged with heavy slurries.	Attenuate microwave propagation and therefore cause drift to measurement.	Attenuate ultrasonic propagation and therefore cause drift to measurement.	Attenuate nuclear radiation and therefore cause drift to measurement.
Color of the liquid	No effect	No effect	No effect	No effect	No effect
Conductivity of the liquid	No effect	No effect	Affects microwave propagation and therefore causes measurement error.	No effect	No effect
Process operation					
Flow changes, turbulence	No effect	Sensitive to flow velocity changes.	No effect	May create errors in the measurements.	No effect
Temperature shocks	Compensation needed. Built-in T measurement and compensation.	Compensation needed. Temperature changes cause error due to impact on the resonant frequency of the sensor.	Compensation needed. Temperature and density are inversely proportional.	Compensation needed. Temperature and density are inversely proportional.	Compensation needed. Temperature and density are inversely proportional.
Pressure shocks	No effect thanks to unique CORE-optics design.	Pressure compensation may be necessary.	May create errors in the measurements.	Pressure compensation may be necessary.	No impact, instrument outside pipe.
Vibration		Vibrations cause noise to the Coriolis force measurement.	Little or no effect.	Vibration may cause noise to the sound measurement.	Little or no effect.

Instrument attributes					
Installation	Flexible installation options in-line, directly to small or larger pipelines, tanks or vessels.	Limited to in-line, and bypasses only in large pipes or tanks.	Directly in the pipeline.	Directly in the pipeline or tank.	Around the pipe. No need to penetrate pipe.
Maintenance	Maintenance-free	Little maintenance	Little maintenance	Maintenance-free	Maintenance and monitoring required.
Maximum operating temperature	150 °C	200 °C	100 °C	120 °C	Any
Operating pressure	Max. 40 bar	Max. 500 bar In low pressures/vacuum. Protective coatings may not tolerate vacuum.	Max. 85 bar	Max. 250 bar	Any
Typical liquid concentration accuracy	±0.1%	± 0.1 ... 0.05%	±0.1%	±0.05%	±1%
Long-term stability	Excellent. No drift mechanisms that degrade accuracy thanks to unique CORE-optics design.	Poor. Pipe deposits, wear, and other drift mechanisms degrade accuracy over time.	Average. Possible drift due to microwave radiation source and detector, and measurement impacted by pipe deposits.	Average. Possible drift in ultrasonic source and detector, and measurement impacted by pipe deposits.	Poor. Notable drift due to radiation source degradation.
Size and weight	Robust compact or probe model ranging from 1.6 to 2.9 kg.	From few kg (U-tube) up to 300 kg models for large pipe sizes.	Starting from 6 kg	Starting from 4 kg	Varies by source, detector, and accessories configuration. From few kg to 50 kg and over.
Recalibration	Factory calibrated, no need for recalibration.	Required due to poor long-term stability. Frequent re-calibration is costly and time consuming.	Recalibration may be needed if measurement impacted by e.g., pipe deposits, wear, or sensor drift.	Recalibration may be needed if measurement impacted by e.g., pipe deposits, wear, or sensor drift.	Recalibration needed due to source degradation.
Verification	Easy on-site verification, traceable to international standards according to ISO 9000.	Traditional methods for verification are both time consuming and disruptive.	Difficult to arrange known reference.	One-point verification possible with water.	Verification difficult due to safety reasons.

Sugar refining and processing

As sugar milling and refining is an energy-intensive process, the goal of sugar refiners is to improve production efficiency while reducing energy and minimizing production costs. To achieve these goals, process control and optimization need to be integrated into the process.

Beet and cane sugar refining and processing relies on several important process parameters such as the measurement of the massecuite solids content of raw and in-process liquids, which is typically defined through a mean aperture (MA) and a coefficient of variation (CV). Also, it is vital for sugar producers to ensure an even quality of crystals, without fines or conglomerates.

To facilitate the even growth of crystals it is necessary to control the sugar crystallization process, which depends on the multivariable function of several parameters.

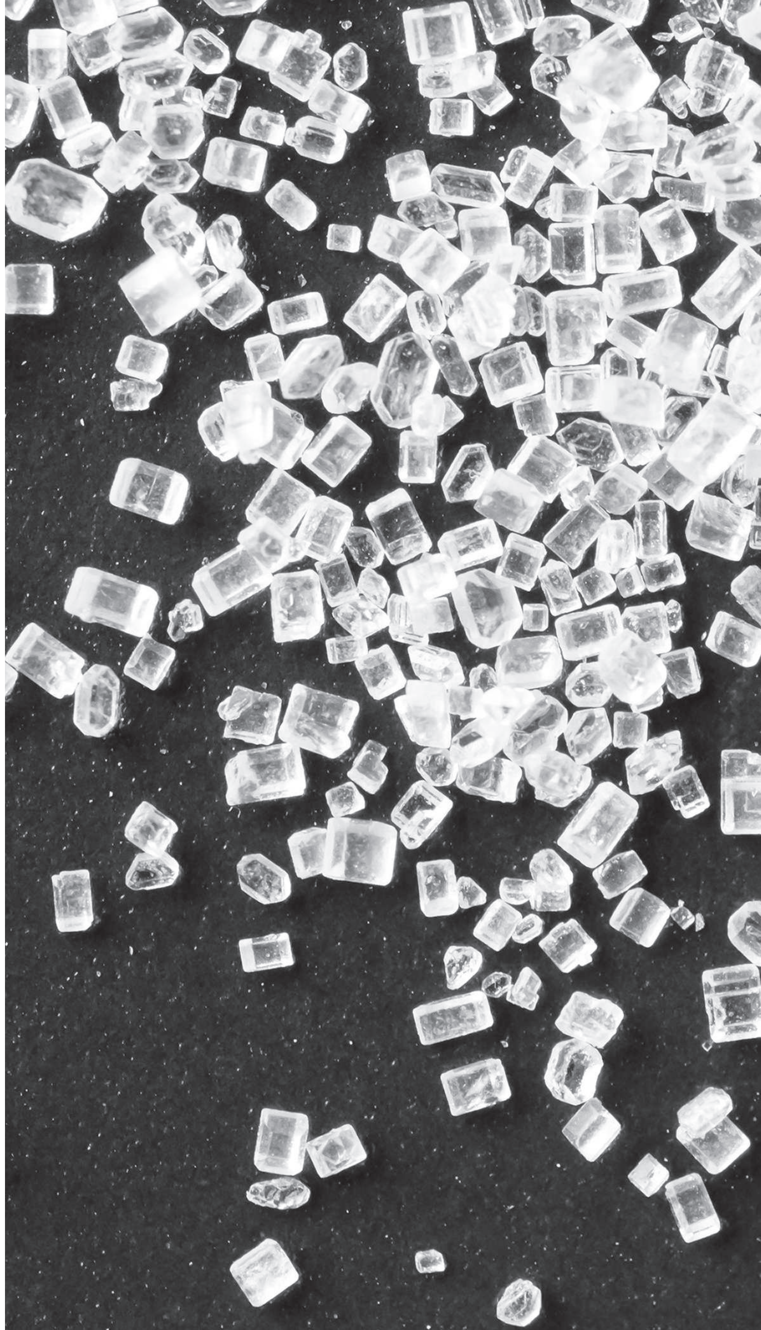
Supersaturation has an optimal range, where sugar crystals grow evenly and widely. Outside this range the crystals will stop growing and may even melt or start to form new crystals, spontaneously creating fines and conglomerates that require reprocessing. It is therefore vital to measure and monitor the concentration of the liquid in the crystallization process. Measuring liquid concentration and density in sugar processing often relies on the use of nuclear density technology. While this technology is accurate and suitable for measuring total solids, including dissolved and undissolved solids, it has several significant drawbacks:

- It uses radiation energy to examine density of a liquid and therefore is not so suitable for sugar mills.
- It is sensitive to bubbles, entrained air, and deposits.
- The instrument presents end-of-life disposal concerns.
- Pipe scaling over time alters readings.
- It requires monitoring and maintenance from a certified Radiation Safety Officer – a costly and time-consuming process.

Another technique used in sugar mills is mass flow measurement with a Coriolis meter. With this technique there are measurement challenges caused by foaming and the entrapped air; density is viewed as a “nice-to-have" meaning true liquid concentration is not taken full advantage of.

To identify the true liquid concentration it is necessary to measure total dissolved solids, and measuring the refractive index with a process refractometer is the only accurate way to do this. The liquid concentration, often seen as Brix content, is calculated based on the RI and automated temperature compensation by a built-in temperature sensor. The inline refractometer also provides a digital output, which offers the following benefits over conventional measurement devices with an analog output:

- Digital signal and digital measurement values for control systems
- No analog/digital signal conversion needed
- More parameters and diagnostics can be collected
- No need for mA calibrations or adjustments of mA ranges



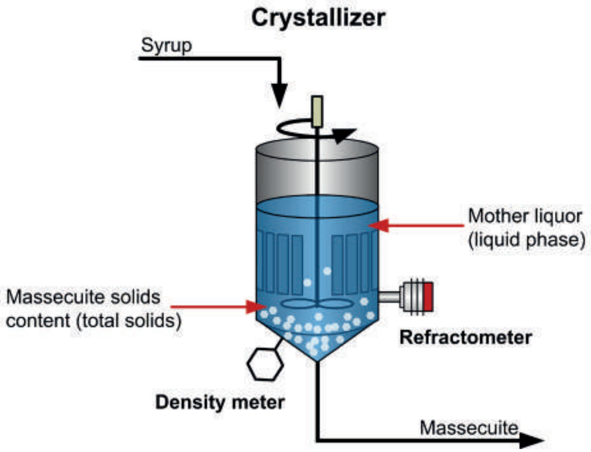
Application case: Beet and cane sugar crystallization

Supersaturation of the sugar solution plays a vital role in sugar crystallization. Supersaturation is a multivariable function of several parameters during only the liquid phase, including syrup or mother liquor. For successful control of supersaturation, it is necessary to monitor the liquid phase as well as the massecuite solids content. For energy-efficient processing and high yield from each strike, it is necessary to ensure just the right degree of supersaturation.

A refractometer is used for selective concentration measurement of the liquid phase over the complete crystallization strike. Due to the digital measurement principle, a process refractometer can measure the true concentration of the mother liquor without being influenced by the sugar crystals or bubbles in the pan. Moreover, a process refractometer does not require recalibration.

Massecuite solids content, or total sugar content, is typically determined using microwave measuring technology. The Vaisala Polaris process refractometer and the supersaturation analyzer SeedMaster-4 provides the following benefits:

- Improved liquid and crystal sugar quality
- Sugar products that are made precisely according to recipe
- Assurance that liquid bulk sugar and molasses meet specifications
- Optimized extraction process by minimizing the usage of water, which needs to be evaporated at a later stage
- Energy savings by adapting product flow to the capacity of the evaporators
- Control over feed juice to adjust the concentration with the capacity of the separation columns; this extends the intervals between recovering cycles, thus prolonging the lifetime of the columns
- Monitoring of supersaturation over the complete strike of crystallization
- Implementation of automatic and accurate seeding of the vacuum pan



Sugar crystallization in a vacuum pan.

Customer case: Sugar refinery boosts profitability with advanced sugar crystallization control

A sugar refinery in Thailand is benefiting from optimized batch vacuum crystallization strikes, crystal quality, and yield through the use of a Vaisala process refractometer together with the Zutora SeedMaster system. The refinery's advanced process control solution was supplied and commissioned by Contrologic.

The ultimate aim of the automation project was to reduce the use of steam and water during the crystallization batch strikes while simultaneously improving sugar quality by keeping the crystal size distribution (CV) and mean aperture (MA) within tight specifications. This was achieved with a fully automated control strategy based on real-time supersaturation control.

Before the implementation, water was used to remove new, unwanted fine crystals. To build supersaturation-based control that would optimize production, the pan was fitted with a Vaisala process refractometer and SeedMaster system to provide real-time data for supersaturation calculation. The SeedMaster is specifically designed for sugar crystallization applications. It consists of a process refractometer and multiparameter monitoring device that provides the parameters necessary for sugar crystallization and enables the implementation of a fully automated control solution.

"Introducing the process control solution not only removed the need to use water, but also reduced steam consumption by about 25% while increasing yield by about 1%."

Customer benefits

Improved product quality and consistency. The quality of the sugar is high and consistent between batches. With optimization, the amount of sucrose in the final molasses is reduced while the CV/MA is improved.

Substantial savings from optimizing raw material and steam consumption. Raw material consumption can be reduced, bringing operational savings, but the biggest saving comes from reduced steam consumption. Prior to implementing an automated control strategy using the SeedMaster, the refinery was consuming 39.4 tons of steam per strike; after implementation steam consumption fell to 29.5 tons per strike.

There is also a cumulative effect, as each step in the sugar production process requires water. Sugar refineries generate the steam used for processing and sell the surplus as electricity to the grid. Controlling and optimizing the production process will allow them to sell more power to the grid.

Less reprocessing of false crystals. When the sugar crystals are of a consistent size it reduces the time and cost associated with reprocessing false crystals.

Fewer labor-intensive tasks. The SeedMaster automates supersaturation control, meaning production staff no longer need to spend time on sampling and other manual tasks.

Vaisala Polaris refractometers and Zutora SeedMaster-4 for advanced supersaturation control

Edible sugar manufacturing is a delicate process that requires process control and instant, accurate Brix (massecuite solids content) measurement of raw and in-process liquids for best product quantity and quality, measured with, for example, mean aperture and coefficient of variation. Only high-quality liquid and crystal sugars are acceptable. In crystal sugar manufacturing, the ultimate goal is to produce the maximum amount of even-quality crystals, avoiding fines and conglomerates.

Efficient raw sugar processing to refined sugar

Sugar production involves two distinct operations: processing sugar cane or sugar beets into raw sugar and processing the raw sugar into refined sugar.

As sugar refining is a highly energy-intensive process where raw juice is subjected to multiple processing steps to remove impurities, the right process control tools help to maximize yield and minimize the cost of production. Overall, the sugar industry is a large water consumer as each production step requires water. The water and energy consumption during manufacturing can be significantly reduced, contributing to the mill or refinery's sustainability, by using modern technology equipment such as Vaisala Polaris process refractometers.

Cover process conditions from liquid phase to massecuite

Sugar crystallization is often the main production process, and mass-producing sugar of consistent quality at a competitive price requires robust measurement devices that are not affected by varying process conditions from the liquid phase to massecuite nor by increasing crystal content during a strike.

Supersaturation is the driving force of crystal growth, and the speed of crystallization depends on this multivariable function of several parameters. Supersaturation has an optimal range, where sugar crystals grow evenly and widely. Outside this range, the crystals will stop growing and might even melt or start to form new crystals spontaneously creating fines and conglomerates that require reprocessing. The Zutora SeedMaster is a unique device specifically created for sugar crystallization and provides the parameters necessary for sugar crystallization.

Learn more about Polaris and Zutora SeedMaster system

How Vaisala can help with your measurement needs

Vaisala has extensive knowledge on how to optimize sugar production to be more efficient.

Read our application examples from beet or cane sugar milling and refining or contact us directly to discuss your process and measurement needs.

Contact us to discuss your application and measurement needs.

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