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All you need to know about in-line liquid concentration and density measurement

eBook for process control engineers

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Introduction

In this eBook, we review and analyze the most commonly used methods for measuring liquid concentration in processing industries such as food & beverage, sugar refining, chemical & petrochemical, and mining & pulp.

Changes in liquid concentration take place many times during the production process and have a direct impact on both the final product quality and the overall efficiency and sustainability of the process. Hence, liquid concentration measurement is a key parameter for controlling and adjusting the process to ensure the desired output.

Process conditions, installation options, environmental impact, accuracy, and overall cost of the solution ownership are all important considerations when choosing the most suitable measurement solution.

There are many analytical process instruments for measuring liquid concentration. However, the focus of this eBook is to compare two of the most commonly used methods of measurement in industrial applications – refractive index technology (refractometer) and density (Coriolis, ultrasonic, nuclear and microwave).

This eBook also provides practical examples of the technology used in various industrial applications and is of interest to process engineers, technology managers, instrumentations engineers, quality control and assurance managers.

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Liquid concentration or density measurement for efficient and sustainable processing

In industrial applications, whenever liquid material flows through pipelines, it must be measured. In this process the liquid composition and concentration of chemicals and/or solids within the liquid change, and measurements of these changes can be used as a key parameter for data-based decision making with regard to process adjustments.

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

In this section we will review the theory and operation principles behind in-line concentration measurement of both refractive index-based measurement technology, and also density-based measurement technology.

Further in the eBook we will present the most important aspects to consider when choosing a suitable measurement solution for various processes.

Finally, we will illustrate the advantages of in-line liquid concentration measurement over density meters using examples from food production, sugar refining, chemical & petrochemical industries, the mining & mineral sectors, as well as pulp mills.

What is concentration and what is density?

Refractive Index and density are fundamental physical properties that can be used to indicate an amount of substance within a liquid – and therefore the liquid concentration. The core difference between concentration and density is that concentration describes how much 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 approximately 1.03 kg/L density (a liter of seawater weighs 1.03 kilograms).

Refractive index and density are physical properties of a liquid. 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 for ensuring product quality, process safety, and overall control, it is essential to evaluate a solution's capital cost 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, the in-line instruments can be field-adjusted against, for example, laboratory reference sample measurements, and thus the fact that the in-line measurement is repeatable and consistent is more important than stand-alone accuracy. Learn more from our accuracy statement.

Long-term stability

How much measurement drift can be tolerated, and how often is it affordable to recalibrate or maintain the sensor? The measurement being robust and retaining its promised accuracy may often be more important than having a superior accuracy specification while not being able to trust the reading after a certain period of time. Also note that the stability of measurement accuracy can be affected by internal measurement drift mechanisms and also by 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 preferably installed directly to the main line or can it be installed on a side-stream? Some instruments and measurement techniques are strictly limited to pipe installations – or even specific pipe orientations or sizes, whereas others offer more flexible options for various installation options, or the possibility to retract the instrument from the pipe without having to interrupt the process.

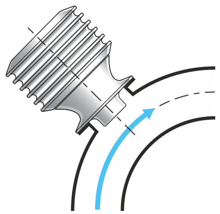
Cost of ownership and return of investments

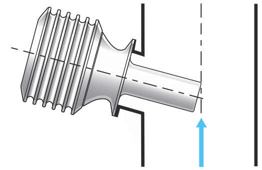
A more accurate and stable measurement instrument may often cost more, but it is important to also consider its recalibration and maintenance costs. Moreover, in many industrial measurement applications a better measurement can provide more savings by reducing raw material or energy use, eliminating product loss, or increasing throughput or yield.

Compact probe for small pipes

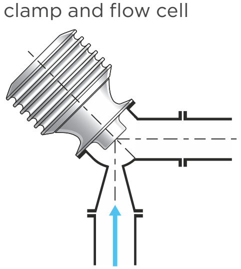
Long probe for large pipes and vessels

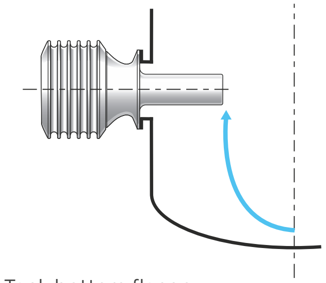
2.5 inch Sanitary or I-Line clamp



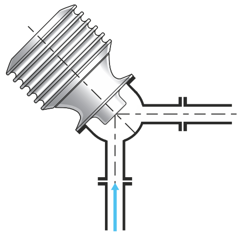


2.5 inch Sanitary or I-Line clamp and flow cell

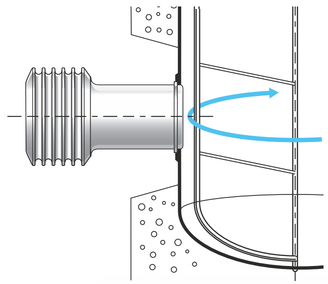




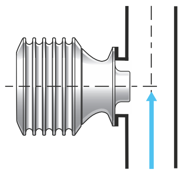
2.5 inch Sanitary or I-Line clamp and flow cell

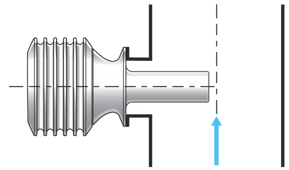


Tank bottom flange



Varivent connection



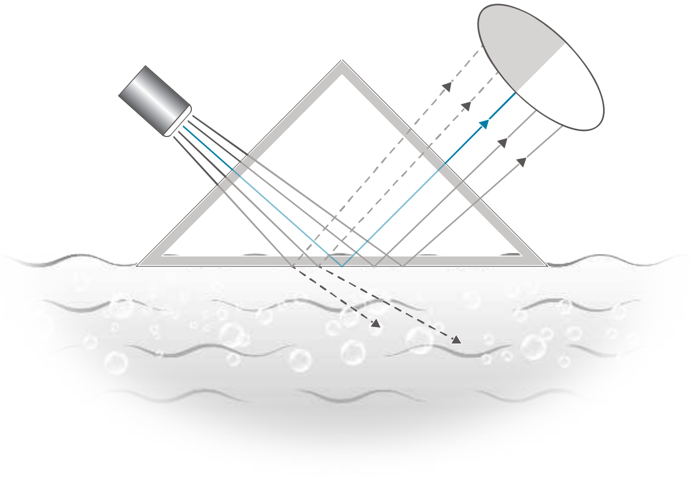


What is a process refractometer?

How a refractometer measures liquid concentration

A process refractometer is based on the principle of the refractive index (RI) measurement, which is a very accurate measurement of the dissolved components in a liquid. The in-line measurement by the refractometer eliminates the risk of solution contamination compared to the manual sampling.

The measurement principle behind the refractometer is the critical angle measurement. There are three main components in the 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 to the image detector and partly refracted to the process. Rays with a low angle are totally reflected to the detector. The angle from which total reflection starts is called the critical angle.



The CCD camera detects a bright field and a dark field corresponding to partly reflected light and totally 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 K-PATENTS® Process Refractometer can indicate different scales, for example, Brix, liquid density, and concentration by weight. The diagnostics program ensures that the measurement is reliable.

The measurement is based on the critical angle measurement, which is why it is not influenced by crystals, particles, bubbles, or the color of the liquid.

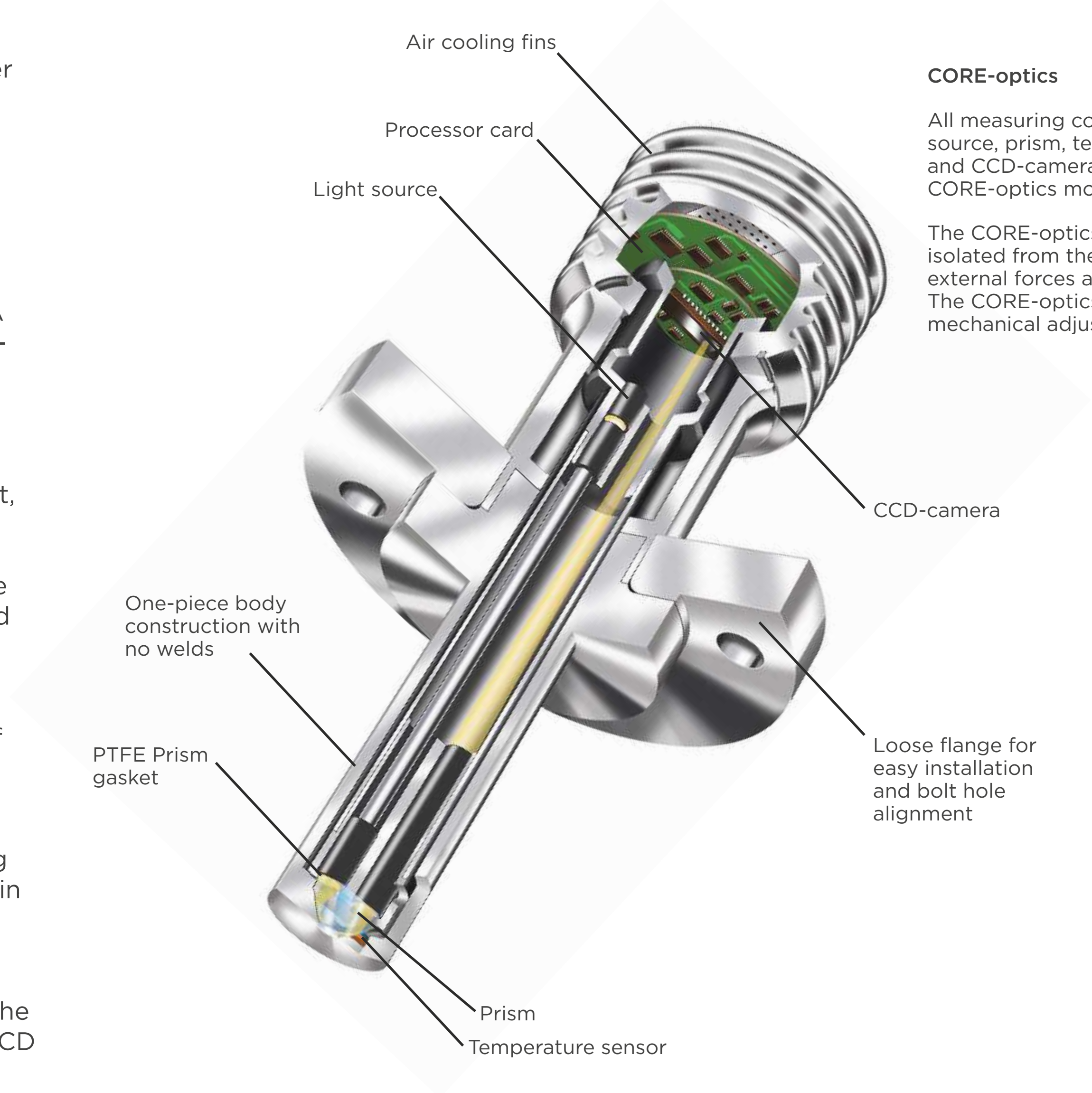
A look inside the Vaisala K-PATENTS Process Refractometer

The Vaisala K-PATENTS Process Refractometer is a standalone device that measures, refines, manages, and indicates Brix and diagnostic information.

The system consists of a compact or a longer probe refractometer and a graphical user interface. It has a measurement range of 0 to 100 Brix and provides an Ethernet or 4–20 mA output signal proportional to the temperature-compensated Brix value, allowing real-time process control.

User interface options range from a durable multichannel industrial computer to a compact, lightweight interface or web-based portal. The refractometer has a built-in web server with a homepage where the instrument can be configured, monitored, verified, and diagnosed via an Ethernet connection. It also provides an mA output signal for control purposes and is identically factory-calibrated to measure Brix and temperature in standard units. Because of the identical calibration, refractometer units can be freely interchanged without optical recalibration. Furthermore, the calibration of each refractometer can be easily verified using standard refractive index liquids and the built-in verification procedure.

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



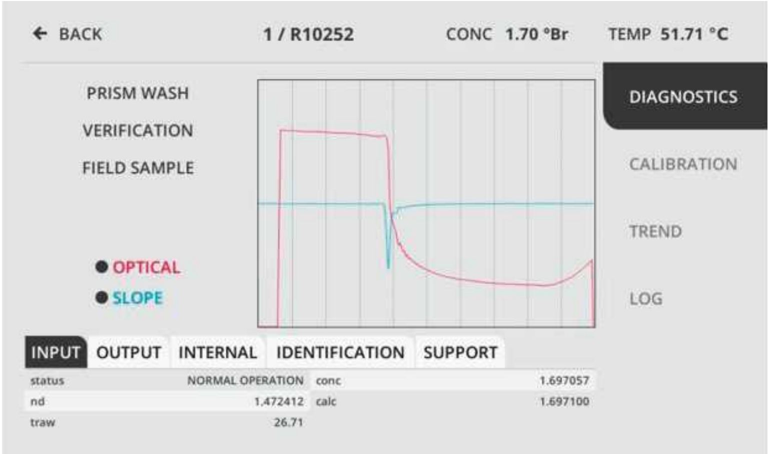
CORE-optics

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

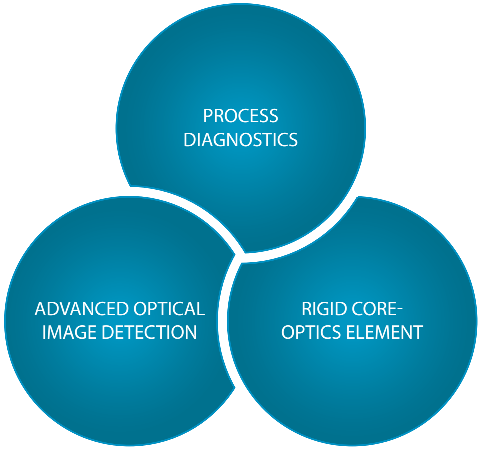
The CORE-optics is mechanically isolated from the influence of external forces and vibrations. The CORE-optics contains no mechanical adjustements.

An optical window into the process

Once installed in-line, the Vaisala K-PATENTS Process Refractometer provides remote access and an overview of the process. The user interface shows the application name, concentration, process temperature, refractive index (nD), serial number of the refractometer, and diagnostic status messages. The diagnostics display on the user interface 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. These functionalities allow for easy remote process monitoring and diagnostics.



Diagnostics display of the Vaisala K-PATENTS sanitary refractometer



Distinctive features of the in-line Vaisala process refractometer

What is a density meter?

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

Coriolis meters

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

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

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

The force sensors in the instrument are prone to vibrations from external sources such as pumps, and 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 sizes and double or triple U-tube configurations are relatively expensive.

Ultrasonic meters

Ultrasonic meters measure the propagation of sound waves in the liquid, typically in the ultrasonic frequencies. As the liquid density affects the sound velocity, the 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 for corrosive chemicals.

The denser the liquid, the more that sound waves moving through it attenuate. Therefore, ultrasonic density meters work best only at a certain range, typically liquids with low density or low dissolved solids content.

While ultrasonic meters are relatively inexpensive and able to be installed vertically or horizontally, bubbles and suspended particles attenuate the meter’s ultrasonic waves, creating noise and reducing accuracy of the measurement. Further, the technique is not optimal for high concentrations, and 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 challenging high-turbidity and high total solids liquids use cases, the equipment is relatively expensive, measurement is disturbed by slurries and bubbles, and for a liquid concentration measurement technique this method has a limited sensitivity and accuracy for low concentrations and small changes. Additionally, pipe coatings can cause drift to the measurement.

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 the protocols can be very complex and costly, and the degrading of its nuclear radiation source reduces the instrument’s accuracy over time.

Comparison of concentration and density measurement technologies

Both density and RI are physical parameters used for measuring liquid concentration and composition.

Types of density meters include, among others, Coriolis, microwave, ultrasonic and nuclear density meters. Each of these can be affected by air bubbles, particles, impurities, deposits, solids, changes in the flow, and turbulence. Temperature changes affect density meters as they need to achieve new 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. Coriolis is good for measuring total solids but not for measuring total dissolved solids. A Coriolis meter primarily measures mass flow. While it can be used for measuring density, the measurement is not very accurate.

In contrast to this, measurements based on RI – such as with the Vaisala K-PATENTS 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, re-calibration, and verification all indicate as-good or better efficiency and performance than with density meters (see the Performance analysis table on the next page).

Table: Performance analysis of density meters and Vaisala in-line process refractometer

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.	Affects twisting Coriolis force of the solution and therefore impacts density reading.	Affects microwave propagation and therefore impacts density reading.	Affects ultrasonic propagation and therefore impacts density reading.	Affects 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 causes drift. May be plugged with heavy slurries.	Attenuate microwave propagation and causes drift to measurement.	Attenuate ultrasonic propagation and causes drift to measurement.	Attenuates nuclear radiation and therefore causes 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 causes error to the measurement.	No effect	No effect
Process operation					
Flow changes, turbulences	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 to 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 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 Kg 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 kilograms to 50kg and over.
Re-calibration	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 deposit, wear or sensor drift.	Recalibration may be needed if measurement impacted by e.g., pipe deposit, wear or sensor drift.	Re-calibration 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 doable with water.	Verification difficult due to safety reasons.

Challenges and opportunities of the liquid concentration and density measurements across various industrial applications

In this chapter we examine the various advantages and limitations of liquid concentration and density measurements using examples from a range of industries.

Food and beverage processing

The food & beverage industry delivers more consumer goods worldwide than any other sector. It is tasked with providing enough food for the growing global population while at the same time producing food sustainably. To ensure that a food product is safe for consumption and can withstand transportation and storage, its shelf-life, including its preserved nutritive value, need to be ensured through careful and consistent processing.

Food & beverage processing involves handling a wide range of liquids. These undergo various processing steps such as cooking, evaporation, distillation, crystallization, spray-drying, etc., each of which change a product's composition. Monitoring of the pre-set product specifications throughout the production process is necessary for ensuring a consistently high quality of the final product. Traditionally, this is done either by collecting samples and analyzing them in the laboratory, or by regularly measuring the liquid's density. Manual sampling is time-consuming; a delay occurs before lab results are known – with the potentially deviating batch moving to the next step before adjustments can be made.

Density measurement is also used in the food industry to define product composition. This is done by measuring total solids in the liquid. However, only true dissolved solids measurement is required for accurately knowing the real-time liquid concentration.

Fruits, vegetables, dairy products, eggs, meat, and fish are among the most consumed food commodities. Their processing often involves liquids that contain soft and hard particles, bubbles, and color. Particles can impact how quickly density measurement equipment wears out, and can also cause filtration equipment damage. The replacement and recalibration of such equipment is factor when determining the total cost of a chosen measurement solution.

Another challenge is the measurement of viscous or foaming solutions as these disturb a density meter's accuracy. Moreover, inaccurate dry solids measurement in a liquid may have detrimental impact on the subsequent processing steps (e.g., evaporation) and cause material deposition on the equipment components. These affect the lifetime of the equipment and add to maintenance costs, and create potentially costly delays in production.

The advantages of in-line Brix measurement

Efficient processing lowers the final production cost and its sustainability by reducing energy consumption and eliminating wastage. The most typical food & beverage processes such as cooking, evaporation, dilution & blending, spray-drying, solid-liquid extraction, alcohol fermentation & distillation, product interface detection, and quality control can be optimized using the in-line Brix measurement of the refractometer.

Moreover, in food and beverage processing, cleaning and draining are required to remove, for instance, acid. The in-line refractometer allows the integration of the wash system with high pressure steam or water. It is also compatible with CIP and SIP cleaning of the facilities.

Below are some application examples in which density is the conventional – but not the most optimal – way to measure liquid concentration. The in-line refractometer method of measurement has a number of advantages, including improved process sustainability, as well as lower operating and overall solution ownership costs.

Application case: Fruit juice blending and concentration

Various nectars and still drinks are produced by blending high quality juice concentrates, water, sugar, and other ingredients. Precise dosing of the juice ingredients is important to achieve the desired taste and concentration qualities. The pre-set Brix is achieved by adding water to the solution. Continuous monitoring of Brix using the in-line refractometer allows for efficient automated processing and juice blending without fluctuations in the concentrate-to-water ratio.

If the Brix value after blending is below the pre-set value, the controller opens the concentrate feed valve to increase the Brix content. Similarly, the controller can add more water if the concentration of the product exceeds the desired value.

Based on the measurement data from the in-line refractometer, ingredients dosing can be adjusted, resulting in a more efficient use of the raw material and more consistent product quality. In this application, as in many other food & beverage applications, the refractometer's measurement is not influenced by suspended solids such as fruit pulp, color, fibers, fruit seeds, or air bubbles.

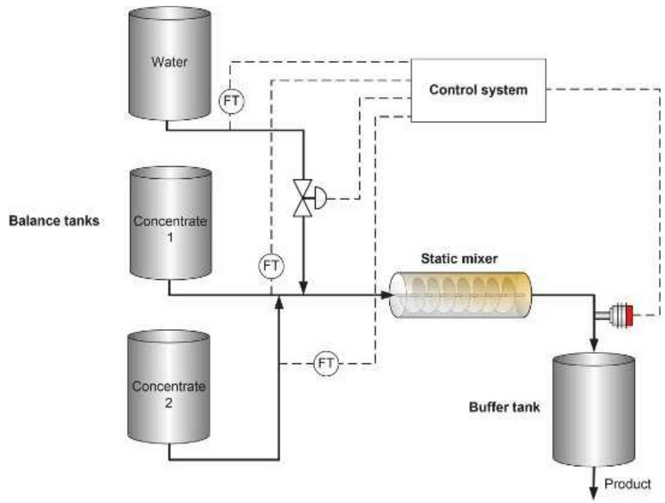
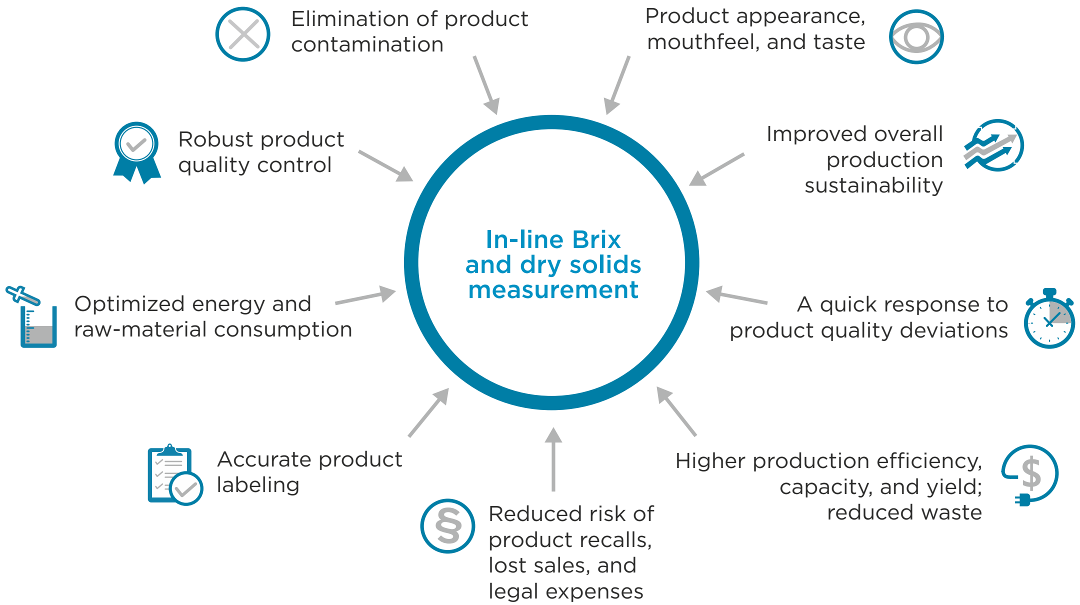


Image: Juice blending with in-line Brix control.



Requiring no regular maintenance or recalibration, the in-line refractometer provides remote process diagnostics and digital output in the concentration unit preferred by the customer.

Learn the details of the juice blending process from the [application note.]()

Making juice concentrate is another example of a process in which in-line Brix measurement offers a range of benefits.

Evaporation is widely used for concentrating juice. This way the vitamins, sugars and minerals from the fruit and vegetables can be preserved, and further juice production from concentrate is easy. Juice evaporation is performed to lengthen the product's shelf life, minimize packing and storage, facilitate transportation, and simplify the handling of the product.

For concentrating fruit juice, a three-stage falling film evaporation plant is commonly used. Evaporation is an energy intensive process, and its efficiency can be improved by setting the concentration of the feed at a certain Brix value. After evaporation, if the Brix value increases, the valve allows a higher product flow rate through the evaporators. This brings the Brix value back to the set-point. In this way, producers can ensure the juice concentrate is manufactured with a consistently high quality.

Fruit juice	Refractometer installation point	Measurement value
Blending	After the static mixer.	▪ Measure continuously the final Brix concentration of the product. ▪ Allows adjustment of the ingredients dose. ▪ Eliminates the need for reblending or penalties due to a too low Brix level. ▪ Minimizes concentrate loss and ensures a consistent product quality.
Concentration	Feed to the evaporator. Directly on the evaporator outlet.	▪ Control of the liquid concentration before the evaporation (usually 9-12 Brix) ▪ Ensure the target concentration is achieved (65 Brix) ▪ Guarantee of a high-quality product ▪ Allows automatic adjusting of the evaporator inlet flow or steam flow to bring Brix value back to the set-point

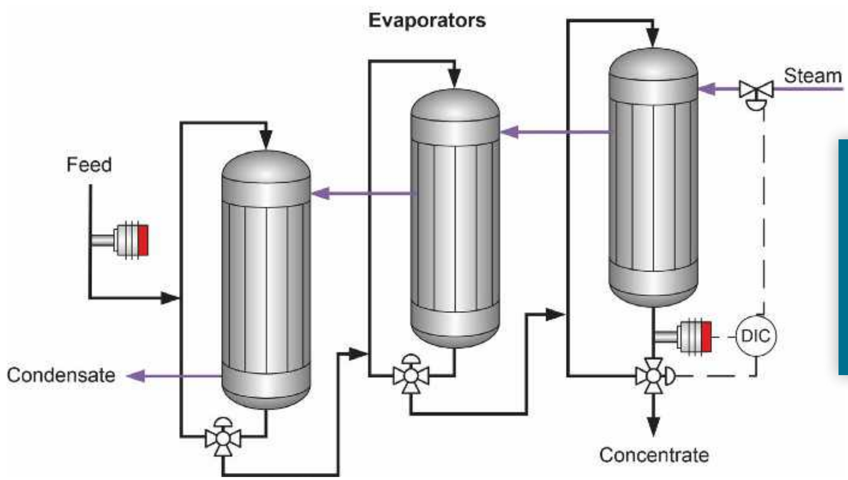


Image: Juice concentration by evaporation.

During beverage blending, there can be fruit fiber or air bubbles that disturb the measurement by the density meter but not the refractometer measurement.

Application case: Beer brewing

Beer brewing is often seen as a craft, since traditionally one had to rely on a skilled sense of taste and smell to ensure product quality and consistency. Today's industrial beer-making is a complex, highly mechanized process that can be streamlined by ensuring that all pre-set recipe indicators are maintained throughout every stage of brewing.

A number of technologies have been devised to monitor various aspects of the brewing process, but some monitoring and measuring methods, such as turbidity and density, can give inaccurate readings because of fouling and interference by larger suspended particles (especially in mashing and the lauter tun) and by the bubbles and foam that are present during most stages. Liquid concentration measurement by an in-line refractometer is therefore preferred, as it provides accurate measurements at every stage of the brewing process without being affected from these interferences.

The customer achieves essential improvement to its beer brewing sustainability, cost savings and final product quality because:

- Water consumption is optimized.
- Energy consumption is reduced through more efficient evaporation, reduction of brewing time and eliminated need to reprocess the wort that would fall out of specifications.
- Waste is eliminated due to fast response time during product/cleaning chemicals/water interfaces detection.
- Assurance there is no product contamination from the CIP.

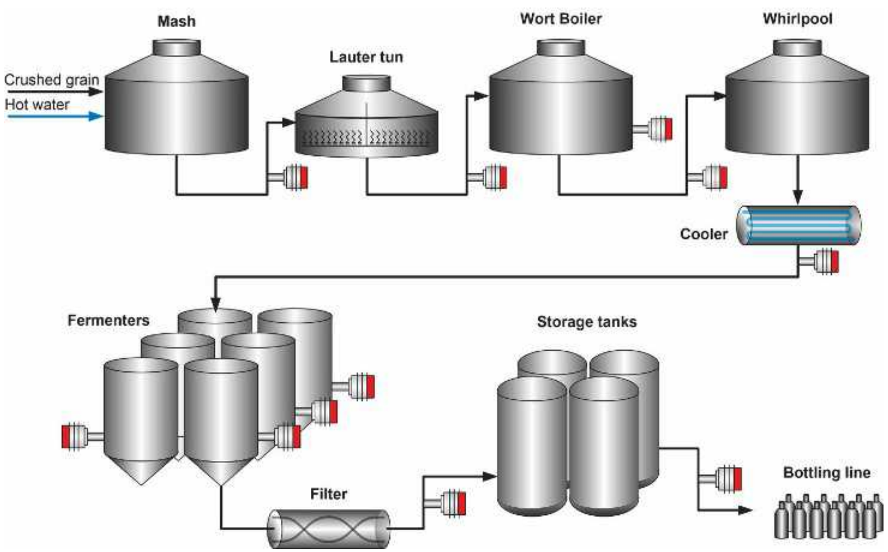


Image: Beer brewing process optimized with in-line refractometer measurements

Learn how [better measurement data helps to produce better beer] in the blog.

Beer brewing	Refractometer installation point	Measurement value
Mashing – creation of the wort.	Outer pipe in the mash tank.	Control of the mash in water as a determination of the final structure of the beer.
Lautering - separating the extracted wort from the spent grain to receive clear liquid wort.	After lauter tun.	Detect the shut-off point for rinsing of the solids to create liquid wort. This prevents the excessive use of water.
Wort boiling – pasteurizing of sweet wort, adding flavorings.	Directly in the wort boiler. After the boiler and prior to the whirlpool.	▪ Continuous measurements of wort strength/gravity to determine the required strength of the wort. This improves beer quality and consistency while helping to optimize brewing time and energy consumption. ▪ To avoid the possibility of processing bitter wort that does not meet the required specification.
Whirlpooling – removal of coagulated residual to form bitter wort.	Before and/or after the whirlpool.	Control of the bitter wort concentration during solids removal.
Cooling	In the outlet of the cooler.	▪ Quality control measure after cooking. ▪ Ensuring that the bitter wort contains the correct level of dissolved solids before fermentation.
Fermentation – conversion of sugars and amino acids into alcohol and carbon dioxide.	Directly in fermenters.	Monitoring of the fermenting progress: ▪ Monitoring the sugars to alcohol conversion rate. ▪ Control of the degree of fermentation to identify the end point. ▪ Indirect measurement of the alcohol volume (%).
Filtration and maturation – yeast settling and removal from the beer. Final opportunity to affect quality of beer.	After filtering.	Final product quality control.
Filling and CIP	At the filling line.	▪ Detection of product-to-product and product-to-CIP cleaning interfaces, allowing efficient change-over between products or batches. ▪ Ensure correct product-to-packaging selection. ▪ Fast refractometer response time when detecting interfaces between product/cleaning chemicals/water, which avoids waste and ensures that no product contamination occurs.

Application case: Infant formula production by wet-mixing process

Wet-mixing is the most used technology as it ensures control over the milk's composition and microbiological safety. The formula's composition should be carefully monitored to achieve a high-quality product that matches as close as possible to breast milk, and which is safe for infant consumption.

An in-line refractometer can be used throughout the whole wet-mixing process to control each of the three steps: preparation of the mix, evaporation, and drying. It is an ideal in-line measurement instrument for safe, hygienic, and accurate manufacturing of infant formula. The refractometer is available with 3-A Sanitary and EHEDG certifications. It is designed to withstand CIP and high process temperatures. Moreover, the refractometer can be calibrated to measure either Brix, dry solids, or Total Dissolved Solids (TDS). The accurate control achieved with such precise in-line concentration measurements ensures a safe, high-quality end product, as well as optimized operating costs.

Access the application note on infant formula production by wet-mixing.

If dry solid content is above 40% or there is low flow velocity, it is possible to install prism washing nozzle with steam.

Infant formula	Refractometer installation point	Measurement value
Ingredients mixing	After the hydration tank to measure TDS content.	This ensures the right in-line dosing of other ingredients to meet the recipe requirements.
	After the heater to monitor the dissolved solids content.	To determine the right dose of heat-sensitive ingredients and ensures that the right concentration is fed to the dryer. Solid content prior drying is critical to optimize the spray dryer performance, energy consumption and final product quality.
Homogenization	After the homogenizer where the fat globules break down to a smaller size.	The refractometer detects fat globules as long as they are smaller than 6 µm.
Drying	Before the evaporator.	For maximum evaporation performance control.

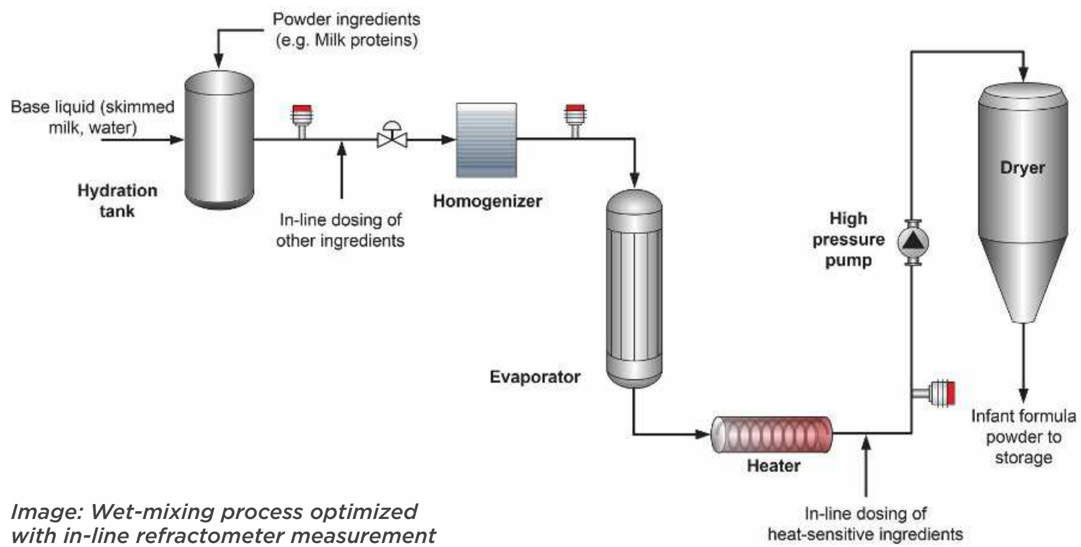


Image: Wet-mixing process optimized with in-line refractometer measurement

Application case: Whey separation

Whey is processed as soon as it is collected to minimize bacterial activity. The process starts with the separation of fines and fat, followed by ultrafiltration (UF). In UF, the whey is passed through a membrane filter to separate the whey protein as a retentate and lactose as the permeate. After separation both products are concentrated through evaporation. For a powdered product, the whey protein is fed to a spray dryer. The lactose is crystallized and separated from the mother liquor by centrifugation and dried in a fluid bed dryer. The final powdered products are then bagged.

The high accuracy control achieved with our precise in-line concentration measurement helps to improve the quality of the final product and to reduce operating costs.

Access the application note on whey separation to learn more.

For more information on the use of the in-line refractometer in dairy applications, check our eBook on dairy processing optimization.

Whey and lactose processing	Refractometer installation point	Measurement value
Whey concentration for ultrafiltration	On outer pipe bend.	To control the correct feed product concentration for the following process step.
Concentration of retentate coming for evaporation	At the evaporator inlet.	To control and adjust concentration levels after the ultrafiltration.
Whey drying	At evaporator outlet.	To optimize energy consumption. It also ensures the correct feed product concentration to the spray dryer or crystallizer.
Lactose crystallization	Directly in the crystallizer.	To monitor the supersaturation of the lactose solution, and to determine the exact seeding point.

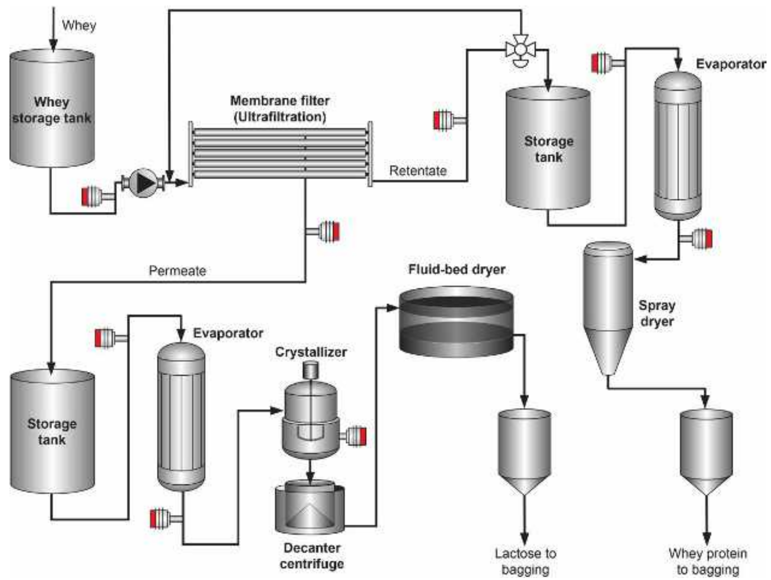


Image: Whey separate process optimized with in-line refractometer measurement

Sugar refining and processing

As sugar milling and refining is an energy-intensive industry, the upper-level 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 rests 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. It is the primary production process that 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 might even melt or start to form new crystals, spontaneously creating fines and conglomerates requiring reprocessing. It is therefore vital to measure and monitor the concentration of the liquid in the crystallization process.

Liquid concentration and density in sugar processing often relies on the use of nuclear density technology. It is accurate and suitable for measuring total solids, i.e., dissolved, and undissolved. However, it also has several substantial 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.

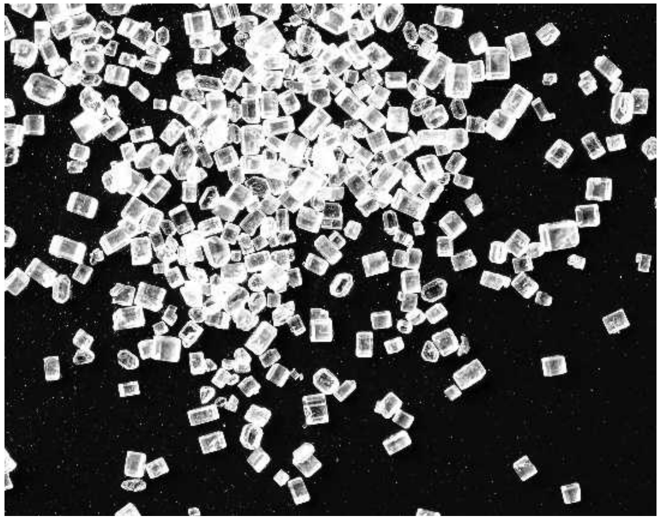
Another technique used by sugar mills is mass flow measurement by Coriolis. With this technique, Coriolis faces measurement challenges caused by foaming and the entrapped air, and thus density is looked at as a "nice-to-have" measurement, and true liquid concentration is not taken full advantage of.

For identifying the true liquid concentration, it is necessary to measure total dissolved solids. A refractive index (RI) measurement by the process refractometer is the only accurate way to measure the dissolved components. The liquid concentration, often seen as Brix content, is calculated based on the RI and automated temperature compensation by the built-in Pt100 temperature sensor. The in-line refractometer provides a digital output which offers obvious benefits over the analog signal of conventional measurement devices.

Application case: Beet and cane sugar crystallization

Supersaturation of the sugar solution plays a vital role in sugar crystallization. For energy efficient processing and high yield from each strike, it is necessary to ensure just the right degree of supersaturation. 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.

The refractometer is successfully used for selective concentration measurement of the liquid phase over the complete crystallization strike. Due to the digital measurement principle, the process refractometer measures the true concentration of the mother liquor without being influenced by the sugar crystals or bubbles in the pan. Moreover, the refractometer does not require re-calibration.



Sugar crystallization	Refractometer installation point	Measurement value
Beet or cane sugar supersaturation control	Directly in the crystallizer.	▪ For selective concentration measurement of the liquid phase over the complete crystallization strike. ▪ For measurement of the total solids content (brix of the massecuite).

Massecuite solids content, or total sugar content, is typically determined using microwave measuring technology.

The system comprising the Vaisala K-PATENTS Process Refractometer and the supersaturation analyzer SeedMaster-4 provides the following:

- An increase in the quality of liquid and crystal sugars.
- 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.
- A monitoring tool of supersaturation over the complete strike of crystallization.
- Implementation of automatic and accurate seeding of the vacuum pan.

Read more about the Vaisala K-PATENTS Process Refractometer and SeedMaster-4 system: Cane and beet sugar milling and refining

Learn more about our solution for sugar supersaturation control.

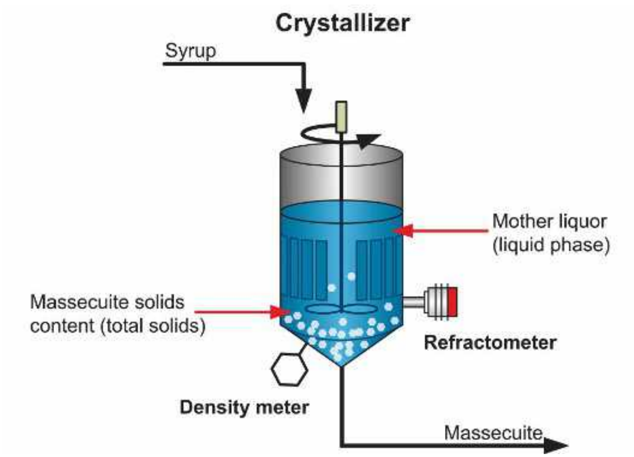


Image: Sugar crystallization in a vacuum pan.

Chemical industry

The chemical industry is one of the largest manufacturing industries worldwide. It produces chemicals that are used as intermediates by other industries (such as the pharmaceutical and food industry) and to make products produced by other branches of the chemical industry. As raw materials, water, air, fossil fuels, minerals and metals are used.

Depending on its final purpose, chemical industry products can be divided into bulk or basic chemicals, fine, specialty and pharmaceutical chemicals. Manufacturing of products according to pre-set specifications ensures their high quality, the efficient use of raw material and optimal production costs. Moreover, process safety is of utmost importance in an industry where hazardous materials are routinely processed.

With the global need for decarbonization, energy-intensive chemical industry is undergoing a transformation – and looking for new ways to save energy during chemical processing. In fact, substantial energy savings can be achieved through the optimization of the typical manufacturing processes.

The chemical industry deals with various liquids which change in concentration as they are being processed. Accurate measurement of liquid concentration produces significant cost savings (see an example calculation later in this eBook).

It is important to measure liquid composition of both raw material as well as finished goods in order to deliver the best quality products.

Set and achieve just the right concentration values to consistently produce a high-quality product – plus reduced product loss and increased revenue.

The in-line Vaisala K-PATENTS Process Refractometer is an ideal solution for chemical processes, as it withstands temperatures of up to 200C and pressure up to 40 bars, and enables remote control and adjustment of the process via its remote diagnostics feature. The in-line refractometer does not drift in response to vibrations. In the majority of applications, it does not require regular prism cleaning, although there is an option for a built-in wash nozzle for applications where chemicals may cause heavy coating of the prism.

Some typical chemical industry operations where the in-line refractometer has been successfully deployed include:

- Reactor, reaction degree, and endpoint determination
- Evaporation
- Dissolving tank or vessel
- Dilution, mixing or blending
- Solid-liquid extraction
- Absorbers and wet scrubbers
- Ion exchangers
- Distillation
- Interface detection and product identification of product-to-product interfaces in loading/ unloading operations
- Quality control

In all of these operations it is of vital importance to accurately measure and identify the chemical in question in order to achieve high product quality, operational safety, cost efficiency, reduced downtime, and sustainability.

Liquid density is often the conventional measure of the change of liquid concentration. There are various ways to measure density. When choosing the best measurement solution, it is important to check how the following factors influence the measurement: process or ambient temperature, air bubbles or impurities.

The application cases below illustrate some of the typical processes in the chemical industry where liquid concentration measurement by an in-line refractometer is an ideal solution that withstands highly corrosive chemical environment, high process temperature and pressure.

The Vaisala K-PATENTS Process Refractometer is designed to withstand harsh, corrosive environments and is available with special wetted parts materials and intrinsically safe and hazardous area certification.

Application case: Manufacturing sulfuric acid, H_2SO_4 by contact process

Sulfuric acid and oleum are produced industrially in contact plants from sulfur-containing gases resulting from such processes as sulfur burning, acid regeneration, or metallurgical operations. The process consists of the catalytic oxidation of sulfur dioxide (SO_2) to SO_3, and the hydration of SO_3 to H_2SO_4 by absorption in concentrated acid. Depending on the number of absorption steps, the contact plants are classified as being either single or double contact process.

Learn the details of sulfuric acid production by contact process in the [application note.](application note)

Sulfuric acid and oleum	Refractometer installation point	Measurement value
Concentration of sulfuric acid, H_2SO_4	At drying tower outlet. At primary and final absorber outlet. After oleum dilution tank.	Monitoring and control of the concentration of acid during drying, absorption and dilution steps to keep the concentration of H2SO4 constant at 93, 98 or 104 % by weight.
	In a control loop.	▪ Measuring the concentration of acid as it gets blended or concentrated. ▪ Control of the acid circulation to the towers to ensure operation within the optimal concentration range, and to maximize the absorption.

In the production of oleum, the final product is viscous with a temperature of 80 °C (176 °F) and containing small air bubbles. This is a source of errors in density and ultrasonic meters. The measurement by the refractometer is not affected by bubbles, color or changes in flow.

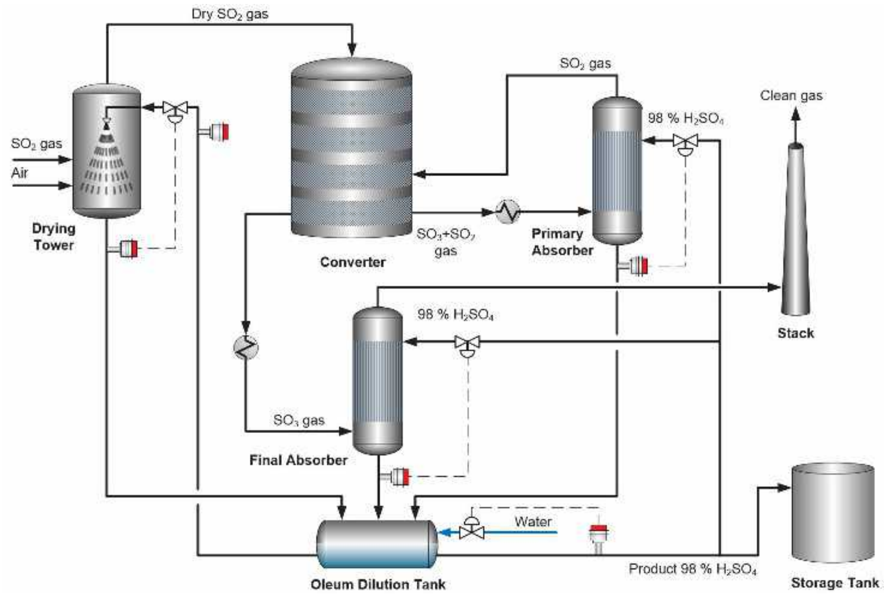


Image: Production of sulfuric acid by contact process

Application case: Nitrile butadiene rubber (NBR) production by polymerization

Nitrile Butadiene Rubber (NBR) is considered to be the keystone for industrial and automotive rubber products, such as synthetic latex. NBR is produced in an emulsion polymerization system. To ensure the required product properties, the polymerization process must be accurately monitored.

The refractometer output signal indicates the degree of polymerization. Each individual polymerization vessel requires the installation of a refractometer to accurately monitor the conversion rate from monomer to polymer.

Get the details of the NBR production by polymerization by downloading the application note.

Learn how the in-line refractometer is utilized to control degree of polymerization in the Control of Polymerization | Vaisala

Application case: Chlor-alkali process

Chlor-alkali is the industrial process for electrolysis of sodium hydroxide solutions. Brine (NaCl in water) electrolysis produces chloride and hydrogen, along with the alkali hydroxide.

Sodium hydroxide is delivered in 30-40 % NaOH concentrations to customers, who then further dilute it with water for use at concentrations of 14-15 % NaOH.

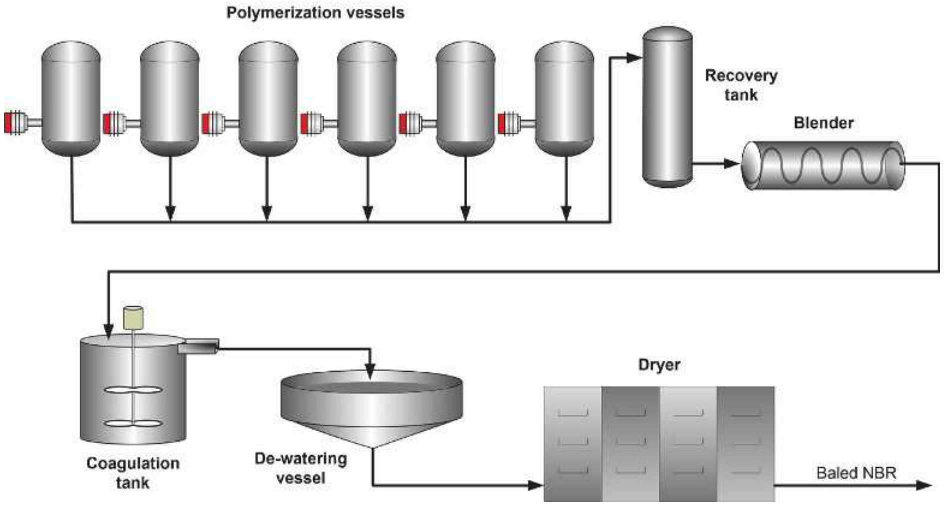


Image: Production of NBR by polymerization

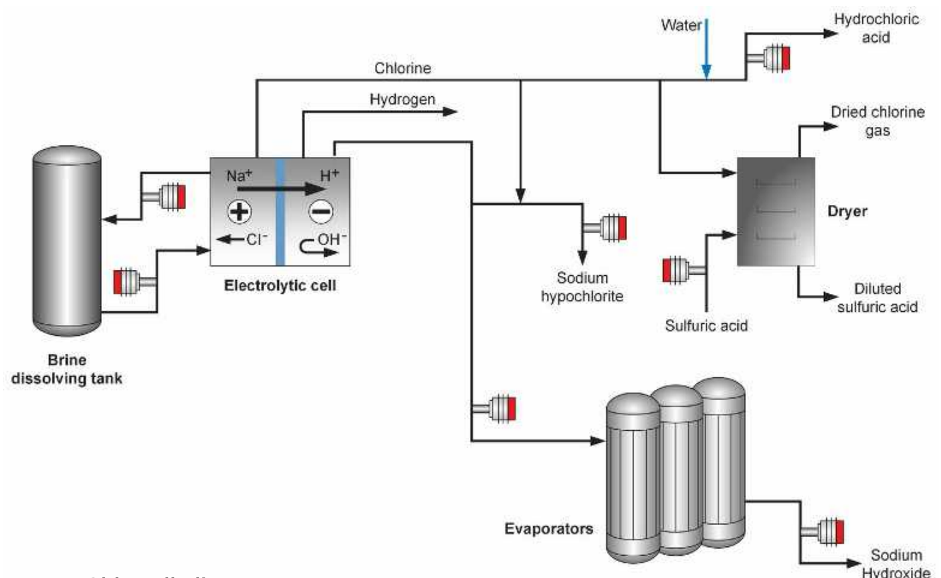


Image: Chlor-alkali process

The Vaisala K-PATENTS Process Refractometer is used to measure the concentration of brine at influx and outflux, which is usually between 190-320g/l. If measured with a density meter, the tube must be very thin to ensure enough sensitivity for accurate density measurement – but this tube easily gets blocked with the impurities in the brine. While coating of the K-PATENTS Process Refractometer prism can occur, this can be remedied with its built-in nozzle that provides an automatic wash with high pressure water. The brine is also corrosive, which is why the material used for the process must be titanium – and a density measurement tube made of titanium is really expensive and difficult to fully clean. Furthermore, once the density tube is disassembled, it must be recalibrated which makes the overall maintenance both expensive and time consuming.

In the chlor-alkali process the main production is sodium hydroxide (NaOH). The in-line refractometer can also be used to measure the concentration of hydrochloric acid (NaCl), hydrogen chloride (HCl), sulfuric acid and sodium hypochlorite (NaClO).

The Vaisala K-PATENTS Process Refractometer withstands strong alkali and highly corrosive environments. It is a perfect device for chemically aggressive solutions and ultra-pure fine chemical processes.

Chlor-alkali	Refractometer installation point	Measurement value
Electrolysis of brine	Influx and outflux of brine. Before the electrolytic cell, and in brine recirculation line. In the product feedline to the dryer.	Measuring concentration of brine. Measuring concentration of: ▪ Hydrochloric acid (NaCl) ▪ Hydrogen chloride (HCl) ▪ Sulfuric acid
	Prior to and after the evaporators.	▪ Sodium hydroxide (NaOH) ▪ Sodium hypochlorite (NaClO)

Example of calculation for revenue optimization for a chemical plant:

If a chemical plant with annual production of 2 million tons of NaOH improves the accuracy of its liquid concentration measurement by 0.1%, the customer can achieve waste reduction of 2000 tons of product which equals to yearly savings of US $ 700,000–1,200,000 (2,000 tons x US $350-600*).

*price of NaOH/ ton from www.made-in-china.com, accessed on March 10, 2022.

Learn more details about the chlor-alkali process in the [application note]

Application case: Chemical interface and product identification in loading / unloading operations

A common application in the chemical industry involves chemical interface detection and product identification during liquid chemicals custody transfer. When receiving or discharging chemicals from a railcar, ship or truck, it is critical to ensure that the right chemical with the right specifications is stored in the right storage tank, and that no product is occurring.

The in-line refractometer identifies the chemicals according to their distinctive Refractive Indices. For example, the figure below illustrates the distinctive refractive indices of hydrocarbons.

The in-line process refractometer provides temperature compensated chemical identification with an accuracy of nD +/- 0.0002 across the full measurement range of nD = 1.3200 –1.5300 corresponding to 0-100 % by weight.

Discover more about how the Vaisala K-PATENTS Process Refractometer supports more efficient and accurate chemical interface documentation and product identification from the brochure Chemical identification and interface detection.

Read more about how our customers achieve cost savings, reduce product loss, and eliminate workplace safety risks with the help of in-line refractometer measurement.

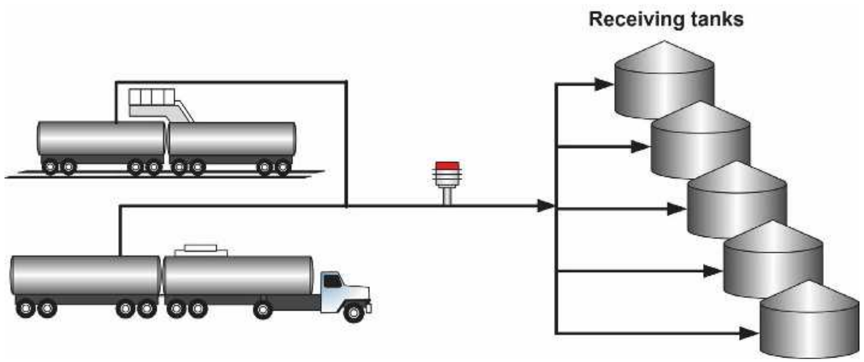


Image: Chemical interface and product identification in loading operations with in-line Vaisala refarctometer.

Did you know that by installing the in-line refractometer for product interface detection you can decrease product waste by up to 30%?

Application case: Caprolactam ($C_6H_{11}NO$) production process

Caprolactam (C6H11NO) is the raw material for Nylon-6 plastics and fiber engineering.

Access the full application note on the Caprolactam ($C_6H_{11}NO$) production process.

Caprolactam	Refractometer installation point	Measurement value
Aqueous caprolactam solution	After the initial extraction.	To control and maintain high extraction efficiency.
Evaporation process control	In the outlet of the evaporator.	Provides a signal to a controller to regulate the concentration value by varying the inlet flow through the evaporators.

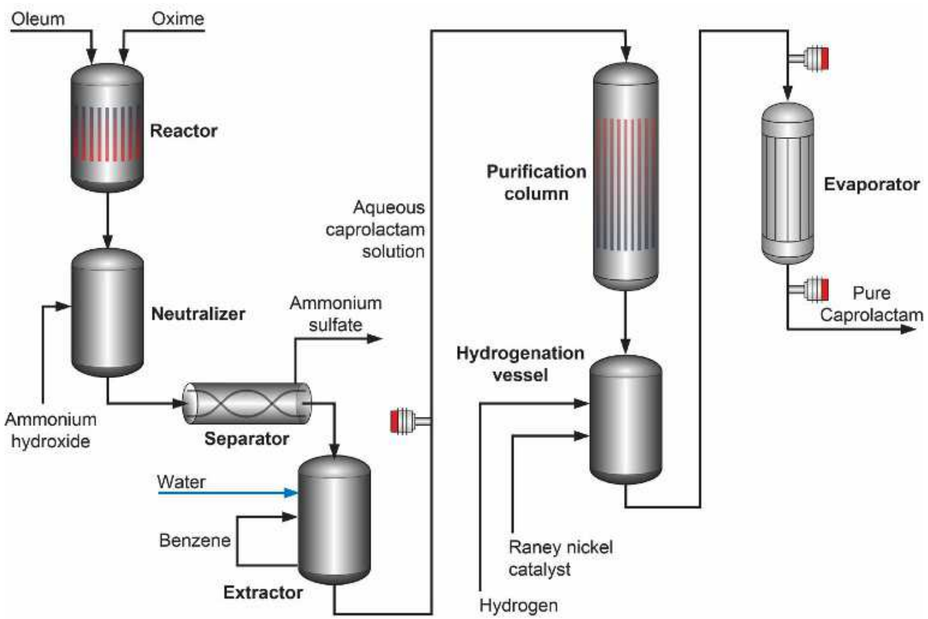


Image: Production of caprolactam optimized with in-line refractometer measurement

Application case: Ammonium nitrate production process

Ammonium nitrate (NH_4NO_3) is a salt consisting of ions of ammonium and nitrate. It is mostly used in agriculture as a high-nitrogen fertilizer. Ammonium nitrate is produced by reacting nitric acid with ammonia. The resulting solution is concentrated to 97.5-98 % in a final concentrator.

Access the full application note on ammonium nitrate production.

Ammonium nitrate	Refractometer installation point	Measurement value
Ammonium nitrate concentration measurement	On the concentrator outflow.	This measurement is critical to create a uniform prill and to prevent the need for reprocessing. ▪ NH_4NO_3 solution is 90-98 %, at a process temperature of 160-180 °C (320-356 °F).
	On the slurry tank outflow.	▪ NH_4NO_3 solution is 90-98 % and the process temperature is 150-160 °C (302-320°F).

The refractometer provides a direct measurement of ammonium nitrate concentration which can be sent to the control room through Ethernet or 4-20 mA output signals. The refractometer's signal warns the operators of changes in the process and allows for real-time adjustments of the process.

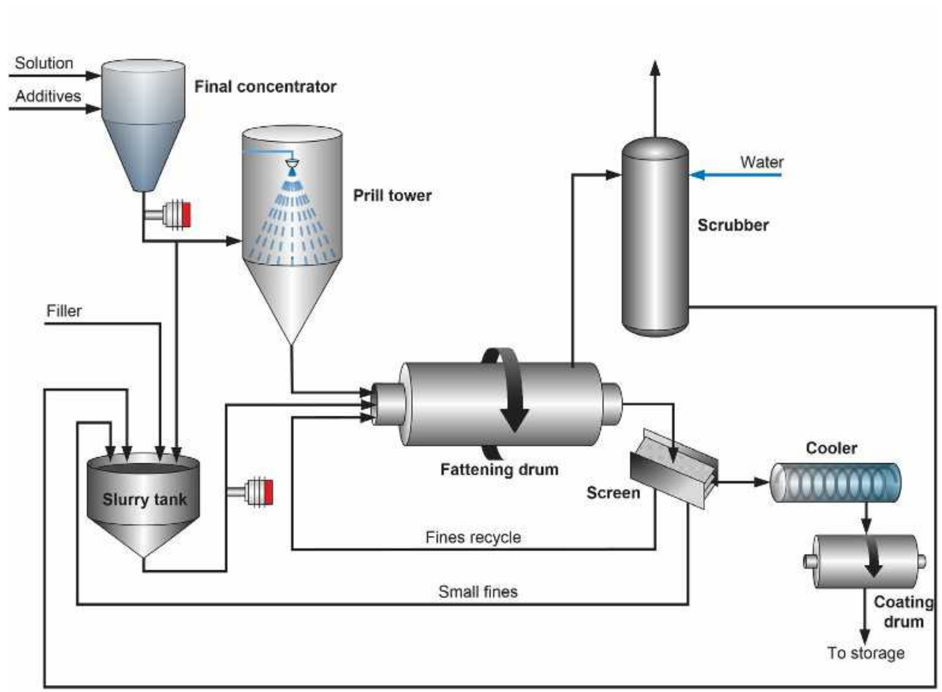


Image: Ammonium nitrate production optimized with in-line refractometer measurement

Kraft pulping: Black liquor and green liquor process

A wide range of consumer products, including paper towels, packaging materials, and hygienic products, are made from the processed material produced in pulp mills – and the journey from tree to consumer is multifaceted. However, in manufacturing one important element applies – in-process measurement. What follows is a review of several measurement technologies and an explanation of the meaning of the term Total Dissolved Solids (TDS).

Chemical control is important in pulp mills, in part because it is a significant cost item. About 99% of chemicals are recirculated, and accurate measurement processes are crucial to keeping this percentage very high.

Black liquor, a valuable by-product of the pulp production process, is used for the recovery of chemicals and also serves as an energy source for pulp mills. Before entering the recovery unit, black liquor is evaporated. Evaporation efficiency is one of the key operations that directly influences mills' production costs. As the pulp industry is in transition towards greater energy efficiency and lower carbon emissions, reducing energy and water use and minimizing production costs is of ever greater interest. Evaporation is controlled by measuring black liquor dry solids. Sometimes a density parameter is used for this operation, but this presents certain limitations and thus the dry solids parameter is preferred as it is accurate and measures exactly how much water is still in black liquor to be evaporated. In addition to black liquor, concentration measurements are also used in green liquor, fiberline, and sulfuric acid residual alkali, and caustic and dissolved ash.

The liquid concentration and density in these applications are sometimes measured using nuclear density technology. While it is suitable for measuring density, it has a number of substantial drawbacks. For example, it uses radiation energy to examine density of a liquid and therefore is not so suitable for pulp mills, in part because it requires monitoring and maintenance from a certified Radiation Safety Officer – a costly and time-consuming process that also involves end-of-life disposal concerns. Further, it is sensitive to bubbles, entrained air and deposits – all of which are present in manufacturing – and pipe scaling can likewise alter measurement readings.

In pulp and paper the Coriolis meter might be used to measure mass flow, however, it often fails due to foaming and the effect of the entrapped air. The Coriolis meter is suitable for measuring total solids when the inside pipe conditions are optimal and do not change. It is notable that during normal operation conditions change constantly. Scaling in pipes and bubbles in a process liquid will give erroneous measurement readings.

Measuring total dissolved solids

A Total Dissolved Solids (TDS) measurement is a parameter which take into account both dissolved and undissolved solids and is considered the only true measurement of dissolved solids. Moreover, the in-line refractometer has a digital output which provides superior benefits over the analog signal.

The Vaisala K-PATENTS SAFE-DRIVE Process Refractometer PR-23-SD is specially designed for the pulp industry. The refractometer is installed directly in the pulp or filtrate line.

TDS changes are detected immediately in the feed and outlet stock lines, as well as in the incoming and outgoing filtrate lines. It is a retractable device, and is designed in compliance with the BLRBAC recommended good practice safe firing of black liquor in black liquor recovery boilers.

Pulp will continue to be more and more important for many producers, and Vaisala offers reliable dissolved solids measurements for various pulp applications. Mills can optimize each step of the pulping process, including cooking, washing and evaporation. In addition, these measurements can be used for advanced process control. The result is clean and stable quality pulp, optimized energy and raw material usage, and savings on operation, water and energy.

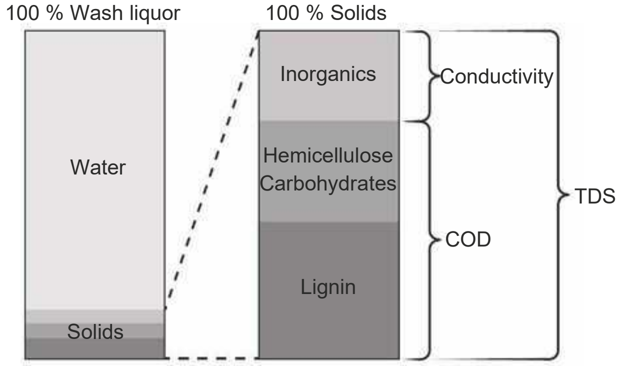


Figure 1: Comparison of measurement methods for dissolved solids in wash liquor.

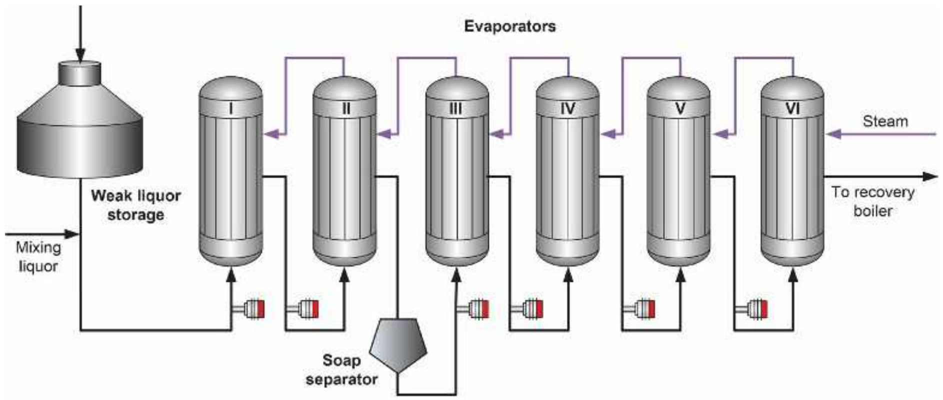


Image: Black liquor dry solids and concentration measurement in evaporation

Application case: Evaporation

Evaporation aims to remove excess water before burning the black liquor, while minimizing total steam consumption.

A refractometer will directly measure how much water is left to be evaporated and report the correct figure to the control system. No conversions are needed.

The feed to the evaporation stage should be as consistent as possible to maximize the capacity and stabilize the output concentration.

Read more in the application note on brown stock washing.

Application case: Brown stock washing

Brown stock washing operation is the key operation effecting the economy of the mill, and thus optimizing the process is critical.

Through optimization of the brown stock washing process and raising the black liquor solids content, mills benefit from immediate profits, cleaner and higher quality pulp for bleaching, and optimized consumption of water, chemicals and energy.

Overall savings can reach 1 000 000 $, with an ROI about 3-4 months.

Read more about how Brown stock washing can benefit from the Vaisala K-PATENTS Process Refractometer.

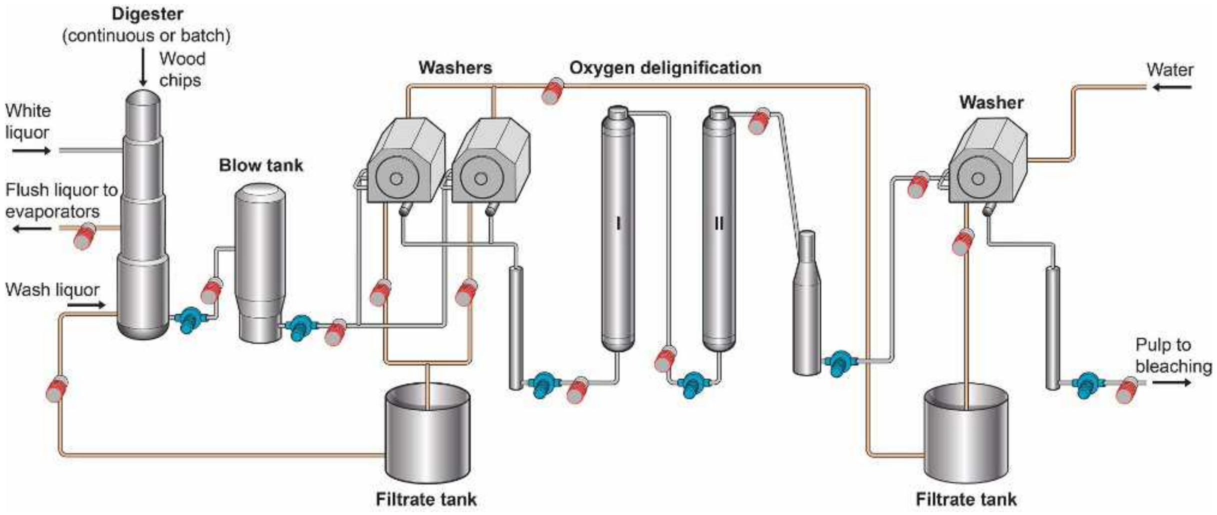


Image: Brown stock washing process optimized with the in-line refractometer

Application case: Recovery boiler

In a recovery boiler, dry solids liquor content required for firing is at least 60%, but preferably more than 65%, to maximize the flue gas emissions, boiler efficiency and energy production.

Too low a concentration of dry solids fed to the burners may result in a steam explosion that may destroy the boiler. To ensure safe operation it is best to use process refractometers and a digital divert system to monitor the black liquor feed to the recovery boiler.

Access the full recovery boiler application note to learn the details.

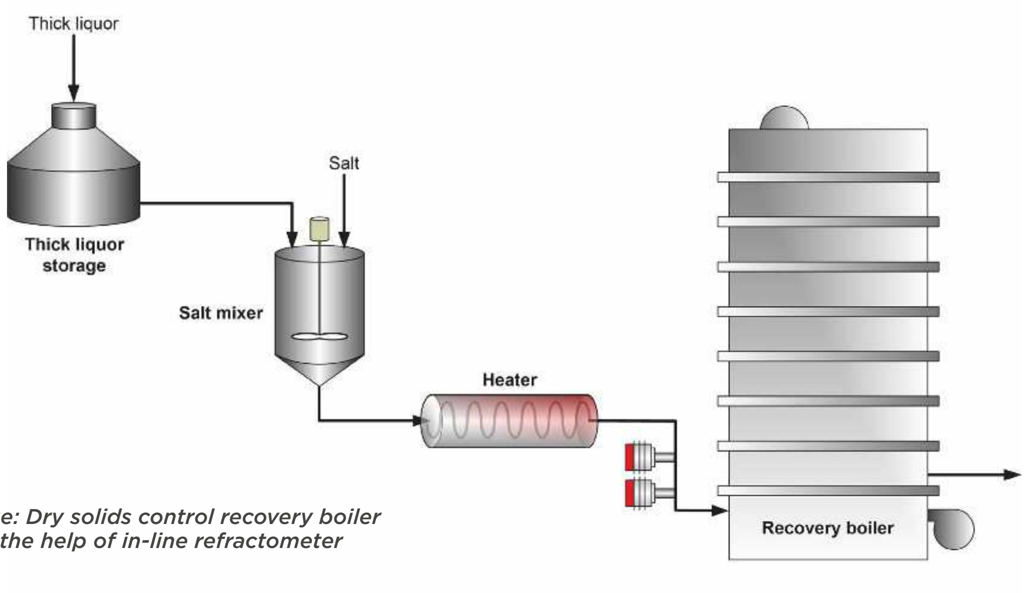


Image: Dry solids control recovery boiler with the help of in-line refractometer

Application case: Causticizing and dissolved ash

The causticizing process is controlled by adjusting the slaker operation, which in turn depends on the concentration of the raw green liquor's Total Titratable Alkali (TTA). The goal is to stabilize the density or TTA concentration in the green liquor feed to the slaker to avoid over-liming and ensure safe operation. TTA measurements in the main green liquor lines (from dissolving tank and clarifier) are required for control purposes.

Efficient causticizing control improves the quality and stability of white liquor, decreases operating costs, and increases pulping efficiency. Well performed lime dosage control reduces the recirculation flow of lime in the process, leading to less lime reburning in the lime kiln as well as decreased energy consumption.

[Read more](#) about the causticizing process in the application note.

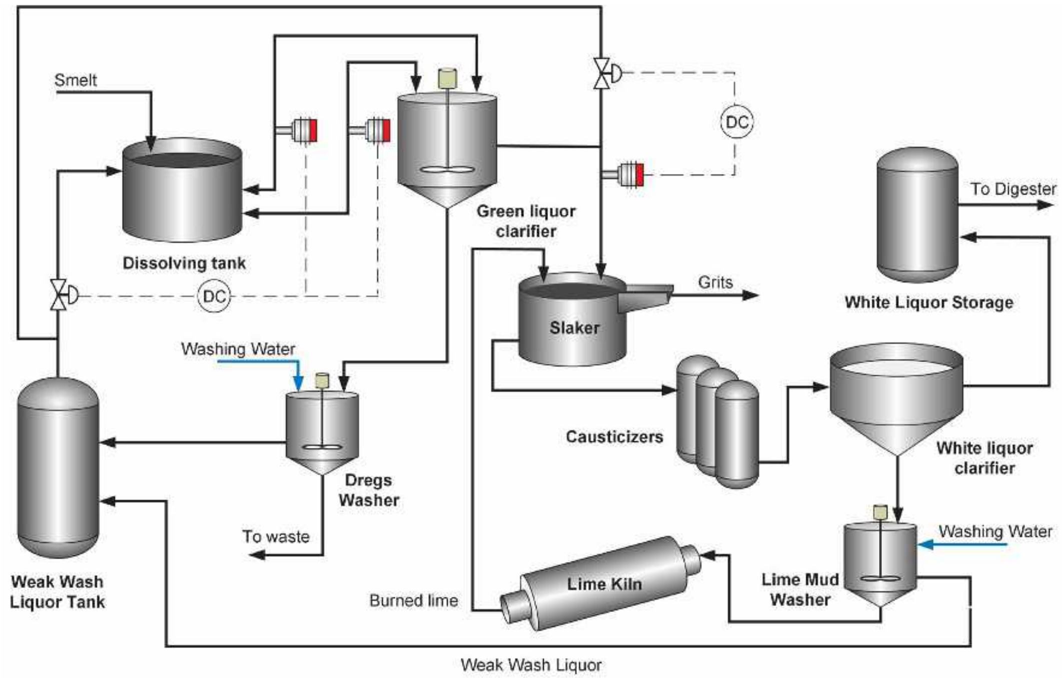


Image: Causticizing control with the in-line refractometer

Table: Kraft pulp process optimization with the in-line refractometer brings cost savings and production efficiency

Application	Refractometer installation point	Concentration measurement value in the process
Fiberline/Brown stock washing	Individual washers, digester and blow line, pulp feed to washers, washing stage, pulp to oxygen delignification, pulp discharge to bleaching.	Through optimization of the brown stock washing process and raising the black liquor solids content, mills gain immediate profits, cleaner and higher quality pulp for bleaching and optimized consumption of water, chemicals and energy. Overall savings can reach 1 000 000 $/€, and the ROI is about 3-4 months .
Evaporation	Feed to evaporation, intermediate liquor, heavy liquor, evaporation outlet.	Evaporation aims to remove excess water before burning the black liquor, while minimize total steam consumption. Refractometer will measure exactly how much water is left to be evaporated giving correct figure to control system. Refractometer will also indicate how the evaporation is operating and signals if there is incrustation or malfunction. Constant feed of solids level of evaporation feed ensures stable operation.
Recovery boiler	2 -3 refractometers in the main black liquor line.	The refractometers measure in-line and constantly the concentration of black liquor, and the divert system controls that the black liquor concentration does not fall under 60 %, which is the safe limit. Lower concentration of dry solids fed to the burners may result in a steam explosion with consequent destruction of the boiler. Other benefits: Maximize boiler efficiency, minimize flue gas emissions. To ensure safe operation, it is essential to use process refractometers and digital divert system to monitor the black liquor feed to the recovery boiler.
Caustisizing and dissolved ash	Green liquor transfer lines, slaker feed.	The causticizing process is controlled by controlling the slaker operation, which in turn depends on the concentration of the raw green liquor's Total Titratable Alkali (TTA). The goal is to stabilize the density or TTA concentration in the green liquor feed to the slaker to avoid over liming and ensure safe operation. TTA measurements in the main green liquor lines (from dissolving tank and clarifier) are required for control purposes. Efficient causticizing control improves the quality and stability of white liquor, decreases operating costs and increases pulping efficiency. Well performed lime dosage control reduces the recirculation flow of lime in the process, leading to less lime reburning in the lime kiln and decreased energy consumption.

We help with your measurement needs

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