Microwave measuring technology for the sugar industry†

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Abstract

Nowadays the dry substance of sugar syrup and massecuite is measured online using the most advanced microwave measuring technology. The correlations for water content and dry substance allow for accurate control of concentration, Brix content and density in all areas of sugar production. This permits a continuous measurement during the complete crystallisation process, both in the solution and the magma phase. This report explains the measuring effect and signal analysis of microwave measurement systems and illustrates the user benefits, resulting in very good process control. Solutions are proposed for typical application problems such as incrustation, abrasion, purity dependencies and the recognition of breaks between crystallisation processes using the Micro-Polar Brix measurement system. Results acquired with different sensors in various processes and applications are presented. Besides the accurate and reliable measurement of all products from sugar beet or sugarcane, a high value is placed on simplicity, low maintenance and easy calibration to ensure optimised process control and cost. The automatic calibration feature, which requires no additional PC, is demonstrated.

Tecnología de medición por microondas parala industria azucarera

Actualmente la materia seca de la meladura y las masas cocidas se mide en línea usando la mas avanzada tecnología de medición por microondas. Las correlaciones para el contenido de agua y materia seca permiten el control adecuado de la concentración, contenido de Brix y densidad en todas las áreas de la producción de azúcar. Esto permite una medición continua durante todo el proceso de cristalización tanto en la solución como como en la fase magma. Este reporte explica el efecto de medida y el análisis de señales de sistemas de medición por microondas e ilustra los beneficios para el usuario que resultan en un muy buen control de proceso. Se proponen soluciones para problemas típicos de aplicación tales como incrustación, abrasión, dependencias de pureza y reconocimiento de problemas en los procesos de cristalización usando el sistema de medición Micro-Polar Brix Se presentan resultados obtenidos con diferentes sensores en varios procesos y aplicaciones. Además de la precisión y la confiabilidad en las mediciones de todos los productos en azúcar de remolacha y caña se tiene un alto valor en la simplicidad, bajo mantenimiento y facilidad de calibración para asegurar costos y control de proceso optimizados. Se demuestra la función de calibración automática, que no requiere un PC adicional.

Mikrowellen-Messtechnologie für die Zuckerindustrie

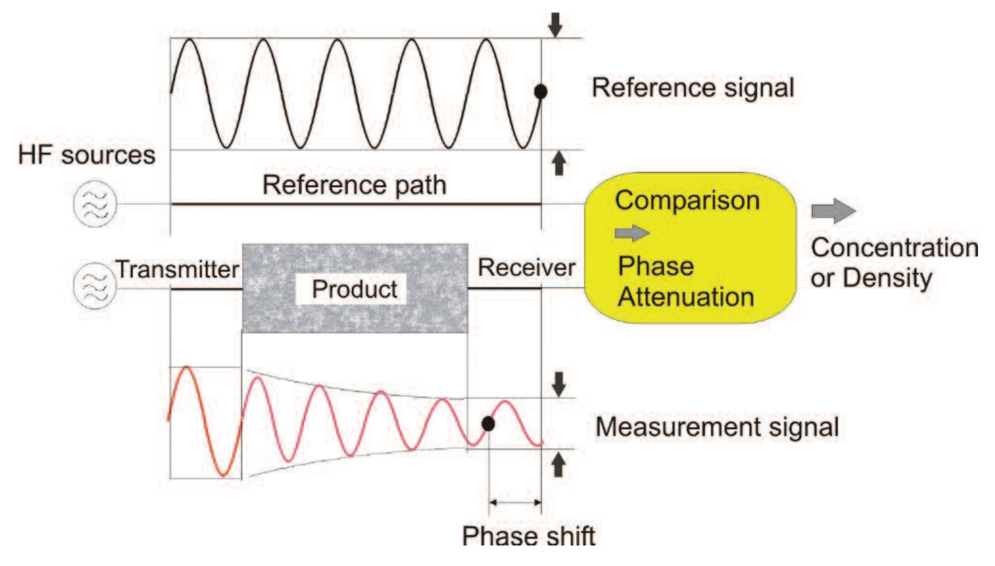
Heutzutage wird die Trockensubstanz des Zuckersirups und der Füllmasse mit Hilfe der fortschrittlichsten Mikrowellen-Messtechnologie online gemessen. Die Korrelationen für Wassergehalt und Trockensubstanz erlauben die genaue Steuerung von Konzentration, Brix-Gehalt und Dichte in allen Bereichen der Zuckerproduktion. Dies gestattet die kontinuierliche Messung während des gesamten Kristallisationsverfahrens, sowohl in der Lösung als auch in der Magma-Phase. Dieser Bericht erklärt den Messeffekt und die Signalanalyse der Mikrowellenmesssysteme und illustriert die Vorteile für den Anwender, die zu einer sehr guten Verfahrenskontrolle führen. Vorgeschlagen werden Lösungen für typische Anwendungsprobleme wie Verkrustung, Abschleifung, Reinheitsabhängigkeit und Erkennung von Pausen zwischen Kristallisationsverfahren unter Einsatz des Micro-Polar Brix Messsystems. Präsentiert werden mit unterschiedlichen Sensoren bei verschiedenen Verfahren und Anwendungen erzielte Ergebnisse. Neben der genauen und zuverlässigen Messung aller Zuckerrüben- oder Zuckerrohrprodukte wird große Betonung auf Einfachheit, geringe Wartung und einfache Kalibrierung gelegt, damit für die Optimierung der Verfahrenssteuerung und Kosten gesorgt ist. Demonstriert wird die automatische Kalibrierung, für die kein zusätzlicher PC benötigt wird.

Introduction

The accurate determination of the dry substance content (Brix content) and/or density is of high importance in diverse sections of a sugar factory. For all of these measuring tasks, microwave measurement technology offers an effective solution. Depending on the process type, the sensor must fulfil special requirements. For example, the sensor must be equipped with a flushing device in the continuous crystallisation processes in order to guarantee reliable measurements over long operating times.

Continuous dry substance measurement is required over the entire crystallisation process. Accurate measurement is required,

Figure 1. Microwave measuring principle



applications, differ in both the frequency range and power. The microwaves used for measuring systems in the sugar industry typically have frequencies of approximately 2.5 GHz and are not very powerful. Table 1 compares the microwave power for several different appliances.

The name 'microwave' is self-explanatory. In a microwave measuring instrument, microwaves from a transmitter irradiate the product as a wave, and are detected by a receiver. If the transmitter and receiver form a single unit, these devices can be of a resonator, scattering sensor or a reflection type. Where the transmitting and receiving units are separate, this is known as transmission measurement. Transmission measurement, such as the measuring technology from Berthold, usually offers a more representative measurement of a product as a result of the larger quantity of product analysed.

The components of a product stream are polarised at varying strengths during microwave transmission through the product, resulting in the microwave signal losing speed and energy. The speed reduction brings about a phase shift in the signal, and the weakening of the energy affects an attenuation of the microwave (see Figure 1). If free charge carriers or polar materials like water molecules are present in the product, this effect is disproportionately increased. The water influence on the signal is around 40-times greater than the influence of other components such as sugar. Hence, it is clear how selectively sensitive the measurement is to water concentration. The correlation between water content and dry substance enables a very precise measurement of the concentration, brix and density in all stages of sugar production.

Table 1. High frequency power for various appliances

Microwave oven	1000 W
Mobile phone	2 W
Micro-Polar Brix	0.0001 W

both in the solution phase up to the seeding point and in the magma phase up to product discharge. This can not be achieved using process refractometers, as measurement is not possible in the crystal phase.

During sugar production, there are other process steps where the determination of the dry substance is very important. This includes measurement of dry substance in raw juice, thin and thick juice. For these applications, special pipe measuring cells are used. Furthermore, the microwave features also make an exact determination of the solids concentration e.g. on milk of lime and the moisture content of crystallised sugar possible.

Microwave systems have been presented before (Klute, 2006). The current report however deals with signal processing and the performance of such systems for the first time and points out the direct advantages for the user.

The characteristics of microwaves

The microwave measuring effect

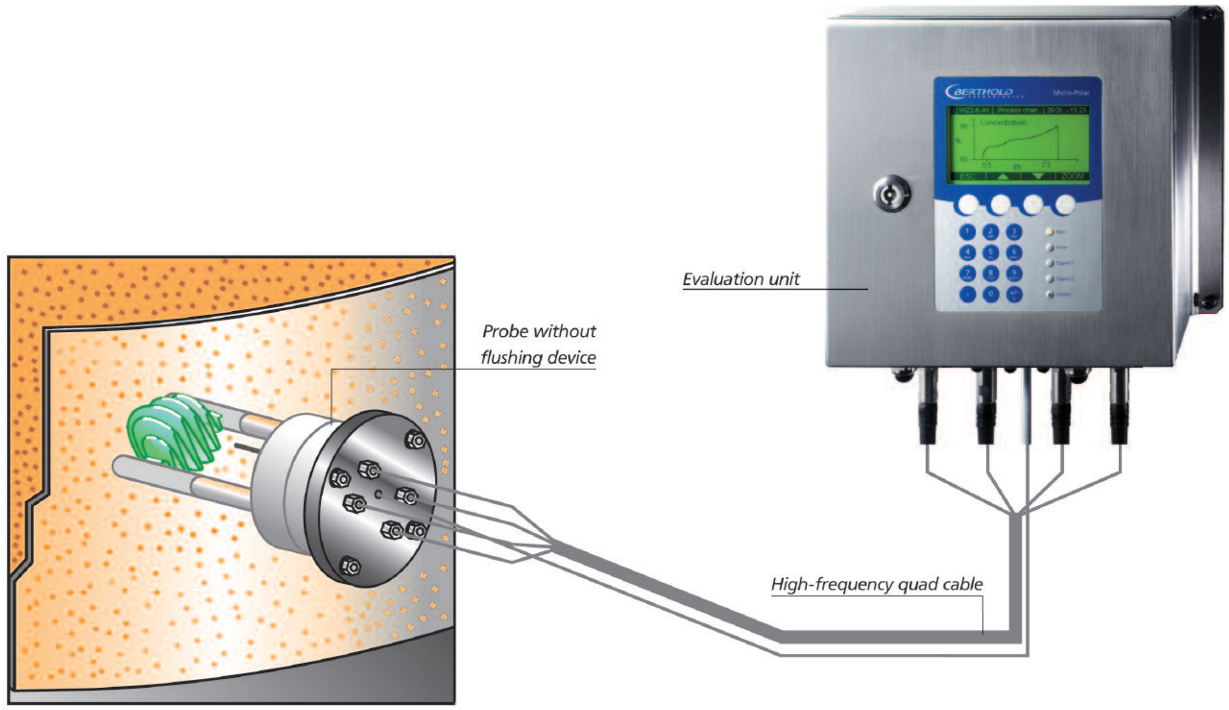
The use of the microwave measurement technique for the determination of dry substance is becoming more popular throughout the world. But what actually are microwaves? Microwaves are electromagnetic waves, similar to those used in radio transmitters, WLANs, mobile phones and microwave ovens. The microwaves used in these

Measuring behaviour in magma

In measuring the dry substance of magma, the microwave measurement technique accounts for the dry substance of the crystals in a similar manner to the dry substance of the solution. For calibration, the microwave signals (phase and attenuation) are referenced to the laboratory analysed value of the sample. If crystals are present in the sample, these must be initially dissolved (by dilution) and the total solids content of the solution determined.

Thus, the microwave system always measures the actual dry substance content, regardless of whether the sugar is in solution or partially crystallised. This results in a simple calibration process as well as a high reliability for use in crystallisation. Calibration samples can be taken evenly spread over the entire crystallisation process, regardless of whether the sugar is in solution or in the magma phase. Two samples are sufficient to determine the

Figure 2. Measuring arrangement in a crystallise



calibration equation, which is mostly linear.

Other measuring procedures are less reliable over the crystallisation process. For example, infrared measurement cannot measure in a crystal solution and radiometric density measurement requires two linear calibration equations, since the measuring behaviour differs in the solution and magma phase.

Possible influencing variables

(A) Crystal size

The influence of the crystal size on microwave measurement is small. The presence of crystal can affect results depending upon the ratio of the wavelength to the grain size. For a wavelength: grain size ratio > 10, the influence is negligible. For the customarily applied frequency of 2.5 GHz, the middle wavelength of the product is 30 mm. Therefore, the influence of grain sizes < 3 mm is quite small.

(B) Sugar purity

The two microwave signals, phase and attenuation, correlate well in most cases and in the majority of applications. Phase is used for the calibration because of the high measurement sensitivity. The measurement sensitivity of the attenuation increases considerably with low purity sugar juices. In such cases, a mixed calibration using both phase and attenuation is preferred, in order to increase the measuring accuracy. This allows the microwave measuring technique to be used with high accuracy for all product purities. The influence of purity fluctuations within a product is negligible.

All product types (A, B and C products) from beet and sugarcane can be measured accurately, reliably, and precisely.

In comparison to this, there is a clear purity dependence and measurability restriction using conductive and low frequency instruments as a result of the different frequency range in use. The low frequency system works within the MHz range and the microwave system within the GHz range.

(C) Colour and turbidity

The influence of material colour and turbidity on the microwave system featured here is insignificant.

(D) Product temperature

The alignment of the water molecules in the microwave field and therefore the concentration/moisture measurement is temperature dependent. The temperature influence is linear in most cases and can easily be compensated.

During the crystallisation process in a vacuum pan, the temperature can vary by a range of 60–80°C depending on the vacuum. The temperature influence in this range is also linear. The evaluation unit from Berthold calculates the temperature compensation automatically after sample taking and provides simple management even in cooling crystallising processes.

Signal processing

The change in wave phase and attenuation caused by the product must be detected and evaluated by very good signal processing. This depends upon good equipment dynamics, unambiguous measurement and stable microwave generation. The equipment dynamics indicate how well the microwave signal can be detected and/or recognised – the higher the dynamic, the higher the measuring accuracy of the instrument. One finds parallels to this in nature: young people have very good hearing; therefore they have higher acoustic dynamic than older people. The equipment dynamic of the Micro-Polar Brix instrument is 70 dB, well over the average of other microwave systems for the sugar industry.

Unambiguous measurement is a basic prerequisite in microwave measuring instruments. Rapid phase changes can occur in the measuring device which may suggest rapid concentration changes are occurring. The wave phase (which can be ± 360°) is responsible for this as it is principally ambiguous. Similar ambiguity can occur with the measurement of time. A glance at a conventional analogue clock does not tell you whether it is five o'clock in the morning or in the afternoon. Additional information is needed, for example the position of the sun or whether it is bright or dark outside.

Micro-Polar Brix solves the ambiguity problem by applying skilful plausibility criteria to the measurement and secures thereby a clear phase. A further option exists to restrict the measuring range.

The measuring system: Microwave evaluation unit and sensors

The microwave system from Berthold consists of two components:

(A) Evaluation unit with high performance processor and microwave generation with DSP technology, in a durable stainless steel housing with graphic display.

(B) Microwave sensor in the form of an insertion probe, pipe probe or with horn antennae.

Figure 3. Microwave sensor, designed as a pipeline measuring cell

Figure 2 shows a typical arrangement with insertion probe. The microwave sensor is always connected by a high frequency cable to the evaluation unit.

(A) Evaluation unit

The compact evaluation unit (digital processor and microwave module) is operated intuitively using soft keys and an alphanumeric keyboard. The measuring signal is transmitted through an insulated 0/4–20 mA current output or alternatively through a RS232 interface. All parameters and calibration data are contained in EEprom memory which is protected against power failure and can be easily replaced.

One sensor is connected to the evaluation unit, which ensures high operation reliability. The distance between the evaluation unit and sensor can be to up to 10 m; allowing the high frequency module to be removed from the very warm probe environment. The compact evaluation unit is certified up to an operating temperature of +60°C. The second high frequency channel is designed as a reference channel and enables very good equipment and cable drift compensation.

The Micro-Polar Brix instrument from Berthold allows the calibration of 4 products. The product switch can be carried out from the keyboard or from a process control room via digital input. Thus, differing products can be run in one crystalliser.

In batch processes, there is great benefit in knowing the crystallisation pause between two processes and issuing the dry substance content without setting time after restart. Micro-Polar Brix enables this by use of the quiescent function in which the current output drops to the lowest current output level when the product is discharged. Only with renewed product entry into the vessel is the dry substance content of the new solution displayed and therefore, fast control is made possible.

For fast and simple start-up, Micro-Polar Brix is set up completely without external PCs. The sampling takes place semi-automatically, without the necessity of manually recording the measured values. The laboratory values are simply entered and the fully automatic calibration calculates the best regression. The laboratory/display result is graphically readable with the correlation degree being indicated.

(B) Microwave sensors

The insertion probe is available in two versions:

1. Insertion probe without flushing device, with integrated PT100.

2. Insertion probe with flushing device, without PT 100.

The unique feature of this insertion probe compared to other probes is the focusing microwave field. The microwave only radiates in the direction of the opposite receiving rod, thus disturbances by changes in the measuring environment are reduced.

The integrated flushing device of the insertion probe is designed in such a way that a very efficient cleaning is effected

Figure 4. Arrangement for measuring the moisture of sugar

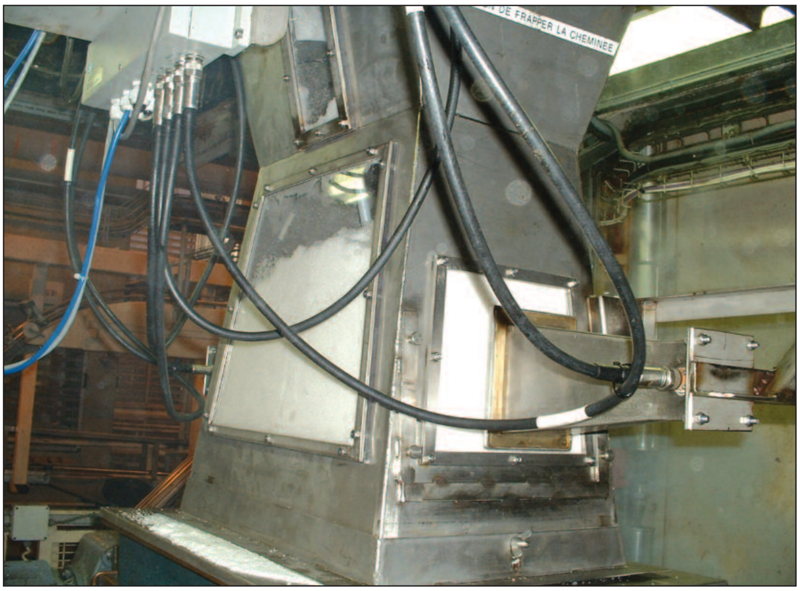


Figure 5. Moisture measurement result

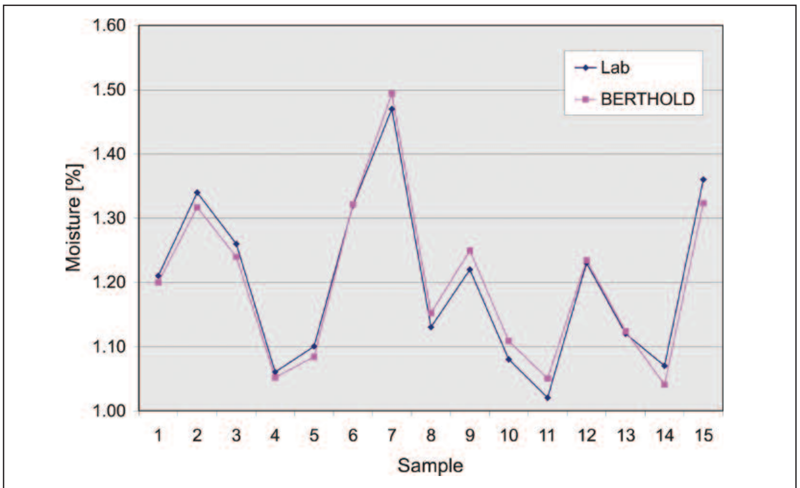
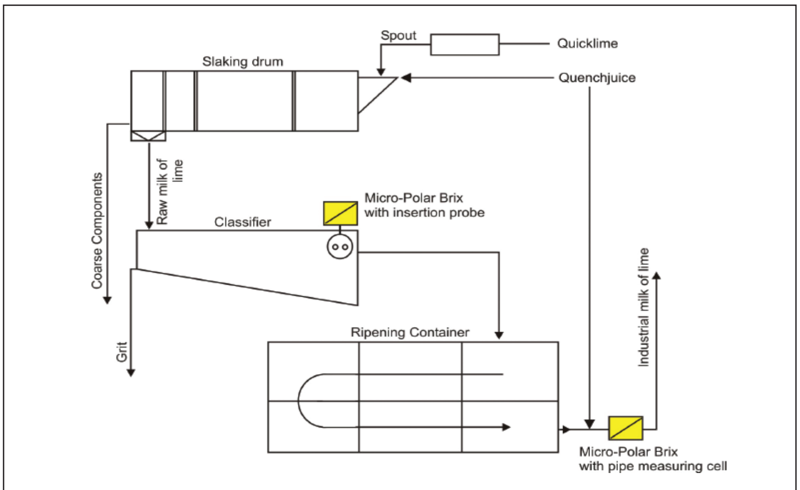


Figure 6. Sequence of milk of lime production



using little washing liquid. The small rinsing flow does not have any influence on the crystallisation process. Thus, a fast signal recovery (few seconds) takes place, ensuring safe process control. The insertion sensors are available in different flange types for ordering; therefore, an exchange is easy when compared to other systems.

The insertion probes are used predominantly in evaporation crystallisers for processing. The standard insertion probe without flushing is used in discontinuous crystallisation processes and the probe with integrated flushing is used in continuous crystallisation processes.

The pipe measuring cell (see Figure 3) is evenly lined on the interior with PTFE, without any protrusions in the measuring pipe. The construction guarantees high abrasion resistance such as for the reliable measurement of milk of lime concentration.

Practical examples in the sugar industry

Microwave instruments from Berthold have been used successfully in diverse applications. These applications include standard applications in discontinuous and continuous evaporator crystallisers; dry substance measurement in raw, thin and thick juices; and a variety of special applications.

In standard applications, accuracies of < 0.2% TS are usually attained; these have been frequently described in the past, e.g. by Mitchell and Springer (2006). Therefore, two specialised applications are described in the following paragraphs.

Special applications

Not only can the water content in sugar syrup/magma be determined using the microwave measurement from Berthold, but a large number of other applications in the sugar industry are possible. Basically, the physics remain the same: we have the material component water with a large microwave measuring effect and a second component with considerably lesser interaction.

Examples of this are the measurement of the solid matter concentration in milk of lime and moisture measurement on crystallised sugar. Both these applications will be discussed further below.

Moisture measurement in sugar cube production

The moisture content of the sugar crystals must be controlled shortly before entry into the form filter used for the production of sugar cubes. The addition of water is controlled by use of the moisture measurement from Berthold. In this case the addition of water takes place before the moisture measuring point. A very exact moisture measurement is crucial for the high quality of the sugar cubes.

Figure 4 shows the measuring instrument. The microwave antennae are installed on a measuring chute. The sugar is accumulated in this chute for the process and therefore, the microwave field is completely filled with sugar.

Figure 7. Installation on raw milk of lime

Figure 8. Insertion probe in the classifier

Figure 5 shows a conformance comparison of a laboratory and microwave measurement (BERTHOLD). The achieved measuring accuracy is < 0.05 weight % moisture with a correlation of 0.969. With the achieved accuracy, a high product quality is guaranteed even without compensating on installations.

Solid matter determination in milk of lime

Raw juice must be separated from the other contents (non sugar substances). These non sugar substances are precipitated by milk of lime addition. The milk of lime (industrial milk of lime with approx. 21 Bé) should be as constant as possible and is manufactured according to the following operational procedure (see Figure 6).

The quicklime coming from the lime kiln is proportioned over a slaking drum into the quenching drum and slaked by the addition of juice (quench juice). After separation of the coarse components, such as stones, the so-called raw milk of lime is led to a classifier in which the so-called grit is separated by sedimentation.

By means of the microwave measurement installed in the classifier (insertion probe, see Figures 7 and 8), large reaction times are avoided and the concentration of raw milk is regulated to a value of approx. 22.5 Bé by variation of the quicklime addition. The measuring accuracy of the microwave measurement is 0.15 Bé for this application.

The classifier discharge is led to the milk of lime ripening container, which consists of several chambers which are successively passed through. The milk of lime which is extracted with a concentration of approx. 22.5 Bé, is measured with a further microwave system and regulated by addition of quench juice to the industrial lime milk. The measuring accuracy can be indicated here as 0.1 Bé.

Generally the pipe measuring cell is used for the concentration measurement of industrial milk of lime. The measuring cell is integrated inline into the existing pipe line system with nominal width of e.g. 65 mm.

Summary

The microwave measuring technique for the determination of dry substance has achieved a lot of acceptance in the last few years in the sugar industry. The pioneering work of Berthold Technologies has contributed considerably to this recognition. The first microwave measurements were carried out during the campaign in 1997 in the sugar factory Jülich, Germany in the evaporation crystallisers for refined sugar 2 and raw sugar.

The microwave measuring technique offers a very exact and reliable measurement of the concentration in all areas of the sugar industry due to its physical characteristics which have been specified here along with the use of efficient microwave systems. The application is not only limited to standard applications such as those in an evaporation crystallisation process for example but is suitable for a large number of specialised applications.

Berthold Technologies has been active in the sugar industry for more than 30 years. The knowledge and the experience from these years form the basis of Micro-Polar Brix. Micro-Polar Brix has proved itself successful in a wide variety of applications and offers a reliable and precise measurement using the most modern microwave engineering, as well as simple and safe operation.

While the possibly harmful effect of mobile phones is occasionally discussed, it can be assured that installations using low energy microwaves have very little effect on humans and the environment, and are absolutely harmless.

The Micro-Polar Brix has a frequency licence approved by both the FCC (Federal Communications Commission) and ETSI (European Telecommunications Standards Institute).

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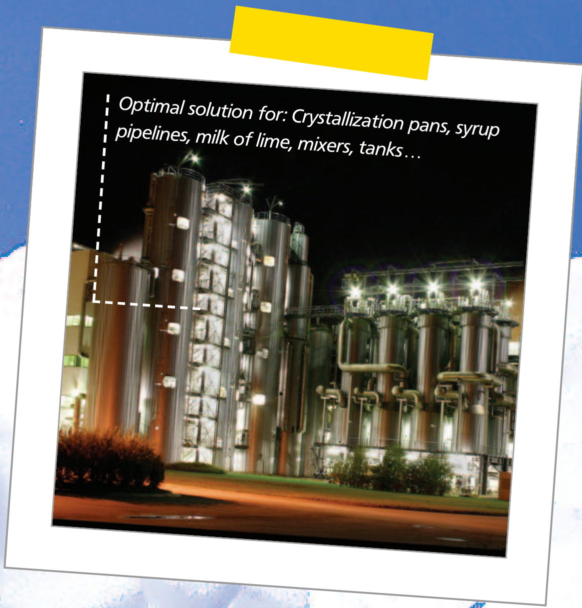


Dolce Vita

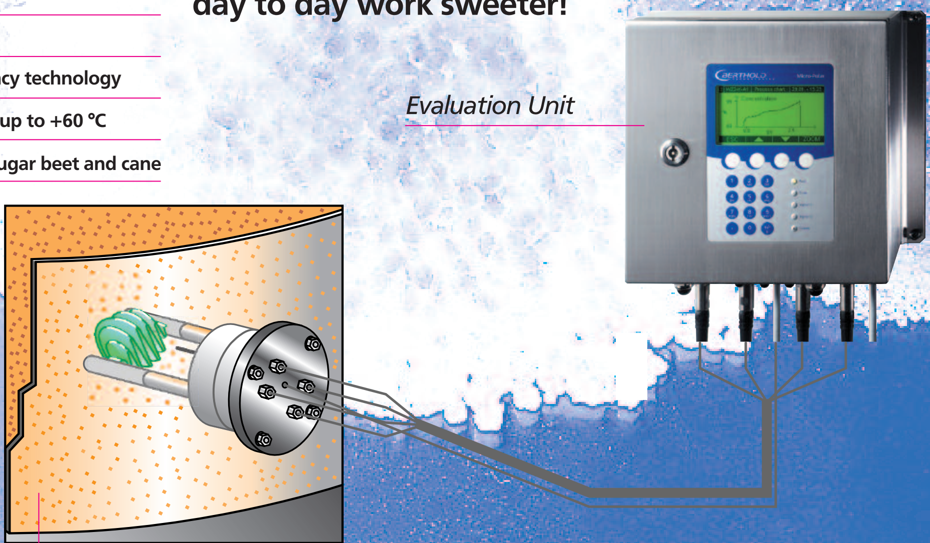
Sugar makes a lot of things in life sweeter. But sugar production is a lot easier if the correct technology is used. For this reason, many sugar producers measure the concentration or density in the crystallizer using the new Micro-Polar Brix from Berthold. Benefit from the fruits of our experience of over 25 years and over 2000 installed systems in the world wide sugar industry that is incorporated in this system. This can make your day to day work sweeter!

Here are the important technical highlights:

- Automatic calibration without a PC
- Crystallisation pause identification
- Graphic, contrast controlled display
- Two HF-generators with multi frequency technology
- For ambient temperatures from -20 °C up to +60 °C
- For A-, B- and C-products made from sugar beet and cane

Concentration measurement in a crystallizer

Density measurement with microwaves



BRIX MEASUREMET WITH MICROWAVE

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