

INTERNATIONAL sugar JOURNAL

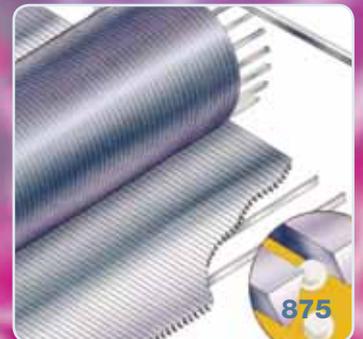
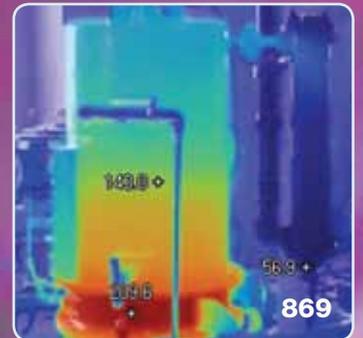
www.internationalsugarjournal.com

December 2011

Volume CXIII: Issue No. 1356

incorporating **Sugar Cane International**

focus: DECOLOURISATION, CRYSTALLISATION AND CENTRIFUGAL SCREENS



Effective colour removal options from cane raw sugar in beet sugar factories

Call for extension to EU sugar quotas from ACP and LDC sugar suppliers

SASRI supports development of GM nitrogen use efficient cane cultivars

Demand for sugar from biochemicals producers increasing

Brazil may import over 1 billion litres ethanol

informa

On-line monitoring and control of supersaturation and other massecuite parameters in vacuum pans: A control engineering approach

L. Rozsa

PROFICON Industrial Controls Ltd., Budapest, Hungary.

Email: LajosRozsa@mail.datanet.hu

abstract

It is generally acknowledged that supersaturation is the most important parameter in sugar crystallization. It has a key role in determining product quality and yield, cost of production, profitability and survival of the manufacturer. Besides supersaturation the other important parameters are: crystal content, mother liquor purity (or purity drop) and massecuite solids content ("brix"). Unfortunately enough, only massecuite solids content can be directly measured by the popular microwave probes. The paper reviews common practice to control crystallization in vacuum pans. Most of them rely on the use of a single probe as the main instrument and on a kind of trial and error method of control. This is due to the fact that there is no single instrument being able to provide on-line data on supersaturation. Claims to the contrary are plainly false, because supersaturation is a function of several variables. The paper presents new solutions and devices (quite a few in use already) for the on-line monitoring of supersaturation based on the data which are needed for its exact calculation. These data can be used not only to implement automatic seeding of the vacuum pans based on supersaturation, but also for the advanced control of the complete strike. On-line monitoring of crystal content, mother liquor purity and other massecuite parameters is also possible.

Keywords: **advanced crystallization control, probes, SeedMaster instruments, supersaturation**

Un enfoque mediante ingeniería de control para el monitoreo en línea y control de la sobresaturación y otros parámetros de la masa cocida en tachos de vacío

Se reconoce generalmente que la sobresaturación es el parámetro más importante en la cristalización del azúcar. Tiene un papel clave en la determinación de la calidad y rendimiento del producto, el costo de producción y la rentabilidad y supervivencia del fabricante. Además de la sobresaturación otros parámetros importantes son: el contenido de cristales, la pureza del licor madre (o caída de pureza) y el contenido de sólidos de la masa cocida (brix). Lamentablemente, mediante las habituales sondas de microondas, sólo se puede medir directamente el contenido de sólidos de la masa cocida. Este trabajo pasa revista a las prácticas comunes para controlar la cristalización en tachos de vacío. La mayor parte de ellas se basan sobre el uso de una única sonda como instrumento principal y en un método de control del tipo prueba y error. Esto es debido a que no existe un instrumento único capaz de proveer en línea datos de la sobresaturación. La información en contrario es claramente falsa dado que la sobresaturación es función de múltiples variables. Este trabajo presenta nuevas soluciones e instrumentos (bastantes de ellos ya en uso) para el monitoreo en línea de la sobresaturación, basados sobre los datos necesarios para un cálculo exacto. Estos datos pueden utilizarse no sólo para implementar el sembrado automático de los tachos de vacío, sobre la base de la sobresaturación, sino también para el control avanzado de la templa. También es posible el monitoreo en línea del contenido de cristales, la pureza del licor madre y otros parámetros de la masa cocida.

Monitoramento e controle on-line da supersaturação e outros parâmetros de massa cozida em painéis de vácuo: Uma abordagem de engenharia de controle

É geralmente reconhecido que a supersaturação é o parâmetro mais importante na cristalização do açúcar. Ela tem um papel fundamental na determinação da qualidade e no rendimento do produto, o custo de rentabilidade da produção, e na sobrevivência do fabricante. Além de supersaturação os outros parâmetros importantes são: conteúdo de cristal, a pureza do licor mãe (ou queda de pureza) e o teor de sólidos na massa cozida ("brix"). Infelizmente, apenas o teor de sólidos da massa cozida pode ser medido diretamente pelas populares sondas de microondas. O documento analisa uma prática comum para controlar a cristalização em painéis de pressão. A maioria deles se baseiam na utilização de um único teste como instrumento principal e em uma espécie de tentativa e erro de controle. Isto é devido ao fato de que não existe um instrumento único que é capaz de fornecer dados on-line sobre supersaturação. Alegações em contrário são claramente falsas, porque supersaturação ocorre em função de diversas variáveis. O trabalho apresenta novas soluções e dispositivos (muito poucos já em uso) para o monitoramento on-line de supersaturação com base nos dados que são necessários para seu cálculo exato. Estes dados podem ser usados não só para implementar semeadura automática de painéis de pressão com base em supersaturação, mas também para o controle avançado completo. A monitoração on-line de conteúdo de cristal, a pureza do licor mãe e os parâmetros de massa cozida também é possível.

Introduction

Sugar crystallization is, and since the start of mass production more than 150 years ago remains a key part and plays a very important role in sugar manufacturing. For quite a long time the undisputed masters of the operations were the “artisan sugar boilers” who kept the process under control relying on their experience acquired during long years spent on the pan floor. The first instruments to assist the pan men appeared around the middle of the last century, but the real control of crystallization remained for a long time the same: manual.

We are witnessing considerable changes since the times referred to above:

- the amount of sugar crystallized and re-crystallized has increased to more than 200 million tons/year;
- the previously closed local markets gave way to a global one;
- energy prices have shot up to unconceivable levels;
- quality requirements from the customers have been considerably increased;
- the cost of manpower increased, while the availability of skilled operators decreased.

These changes have been accompanied by profound changes in the area of a new discipline: instrumentation and automatic control of processes in a wide range of industries.

Mass production of any competitive product should rely on:

- up to date (or almost up to date) machinery in the technology,
- familiarity with the process to be controlled,

Table 1. Important massecuite parameters and what is actually being measured by the common instruments

Important parameters	Instruments commonly used
Supersaturation	None
Syrup and massecuite solids content	Microwave, (nuclear)
Crystal content	None
Mother liquor purity	None
Mean crystal size	None
Syrup and mother liquor concentration	Process refractometer, (boiling point elevation)

Table 2. Instruments in use and the parameters governing their readings

Instrument (Sensor)	Variables governing the reading
Conductivity	f (Liq. conc., Temp., Cryst., Ns.)
Radio Frequency (RF) resistance	f (Liq. conc., A, Cryst., Temp.)
Radio Frequency (RF) capacitance	f (Liq. conc., A, Cryst., Temp.)
Nuclear (density)	f (Liq. conc., Cryst., Temp.)
Consistency	f (Visc., Cryst.)
Microwave	f (Liq. conc., Cryst.)
Process refractometer	f (Liq. conc.)
Liq. conc.: liquid concentration	Ns.: non-sugar (content, composition)
Temp.: temperature	A: ash content
Cryst.: crystal content	Visc.: viscosity (f (Liq. conc, Temp., Ns.)

- well selected instruments and control equipment,
- experience in automatic process control.

It is not easy to meet all these requirements. Some of them reflect what can be briefly termed as: control engineering approach.

Monitoring sugar crystallization

Sensor selection

The only purpose of measurement is control. When talking about measurement and control, in our case about the control of crystallization, besides supersaturation - the most important parameter to monitor and control - there are other ones as well which can provide important information for the control system or the technologist on the process of crystallization.

Table 1 lists the important massecuite parameters and the instruments available to provide on-line information on them. The table shows that there are only two which can be monitored directly:

- massecuite solids content (brix) with the popular microwave probes (the nuclear probes are banned in quite a few countries),
- and mother liquor concentration using process refractometers (measurement of boiling point elevation depends on purity and is not accurate enough (Saska, 2002).

In Table 2 the instruments commonly used in crystallization control are listed (Rozsa 2003). The output of these instruments is in most cases a function of several independent process variables.

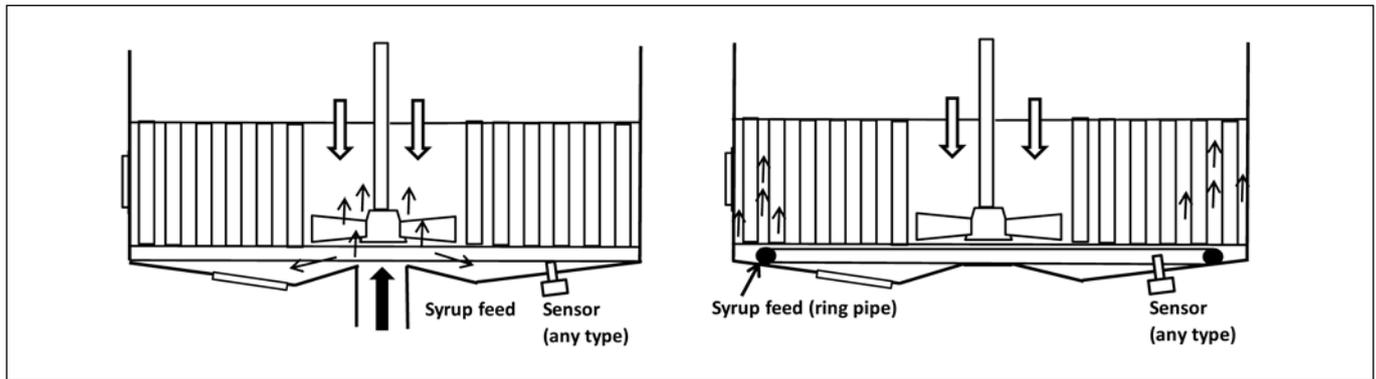
Comparing the data in the two tables it can be concluded that there are only two sensors which provide information on one of the important massecuite parameters and are not influenced by other process parameters, the:

- microwave sensor, which measures the total solids content (brix) of the massecuite, and
- the process refractometer, which selectively measures the concentration of the syrup / mother liquor during crystallization.

The other sensors listed in Table 2 do not provide information on the parameters listed in Table 1: data on RF capacitance or resistance for example fail to give accurate enough information that could be used for reliable and repeatable seeding and boiling control (Radford and Cox 1986; Rozsa 1997).

Automatic control of crystallization should be based on instruments that are able to provide reliable and representative on-line data on the parameters that really

Figure 1. Outdated (a) and preferred (b) feed solution inlet arrangements



count. Instrument selection therefore is a key issue and is a major component of the control engineering approach.

Sensor location

It is vital to use representative data in any type of control operation. There is a large number of papers and research reports on the nature and importance of massecuite circulation in a vacuum pan. However, it is surprising to find the general lack of interest on sensor (any type of sensor) location selection. There are two main requirements to meet:

- the volume around most of the sensors should be free of bubbles (vapor or gas), and
- the measured parameter should be as representative for the full volume of the massecuite as possible.

Disregarding the downtake, where most of the sensors cannot survive, the only bubble-free area is under the calandria.

Figure 1a shows a pan design which is at least 70 years old and is a bad example indeed. Syrup feed not only works against the main flow of circulation, but due to its closeness to the sensor head will result in completely false data coming from a diluted and relatively small volume. These certainly cannot be regarded as representative for the much larger volume of the massecuite.

This design completely disregards one of the basic requirements of good control: reliable and representative measurement. Spending a lot of money on an expensive control system while supplying it with false data is a clear waste of money and time. The most surprising is however, that a new refinery in construction right now will use this pan design.

In Figure 1 b syrup is fed into the pan by a ring pipe under the calandria, directing syrup flow upwards close to the pan wall. This arrangement not only assists circulation, but makes the sensor readings much more representative as well.

Supersaturation: the most important parameter

Definition

Supersaturation (SS) is defined as follows:

$$SS = f(\text{Conc.}, \text{Pur.}, \text{Temp.}, m, b, c) \quad (\text{Eq. 1.})$$

A closer examination reveals that supersaturation is a multi-variable function:

$$SS = \frac{\text{sugar in solution (g / 100 g water)}}{\text{sugar at saturation (g / 100 g water)}} \quad (\text{Eq. 2.})$$

(both at the same temperature)

Conc.: liquid (syrup / mother liquor) concentration;

Pur.: liquid (syrup / mother liquor) purity

Temp.: temperature;

m, b, c: feed syrup quality parameters (Rozsa 2000)

From Equation 2 it is evident that there is no instrument capable of providing reliable information on supersaturation based on the measurement of a single process variable. It can only be calculated on-line based on information on the variables which govern it. It is therefore really surprising to find reports in the relevant literature and in the brochures of some control system vendors on the use of conductivity, microwave, RF, or density sensors dubbed as "supersaturation sensors". These claims are certainly false and misleading.

It is well known that there is a limit value of supersaturation, above which nucleation will start. Various authors give different data for this limit between 1.12 and 1.35, more recent data give smaller values of between 1.12 and 1.15. Exceeding the limit results in the formation of new crystals in the presence of already existing ones (for example: seed crystals; this happens during shock seeding). The range of operation regarding supersaturation can be determined as follows (Rozsa 2008):

Saturation: SS = 1.00

Start of nucleation: SS > 1.12...1.15

Typical values when seeding: SS = 1.06...1.08 (full)

SS > 1.15 (shock)

High limits after seeding: SS = 1.10...1.12 (high pur.)

SS = 1.12...1.15 (low purity syrups).

It is evident from the data above that the normal range of operation is quite narrow: between SS = 1,00 and SS = 1,12...1,15. Exceeding these limits will result in serious consequences: in the dissolution of the already crystallized sugar, or in the formation of fines and conglomerates.

Figure 2. Recycling of already crystallized sugar

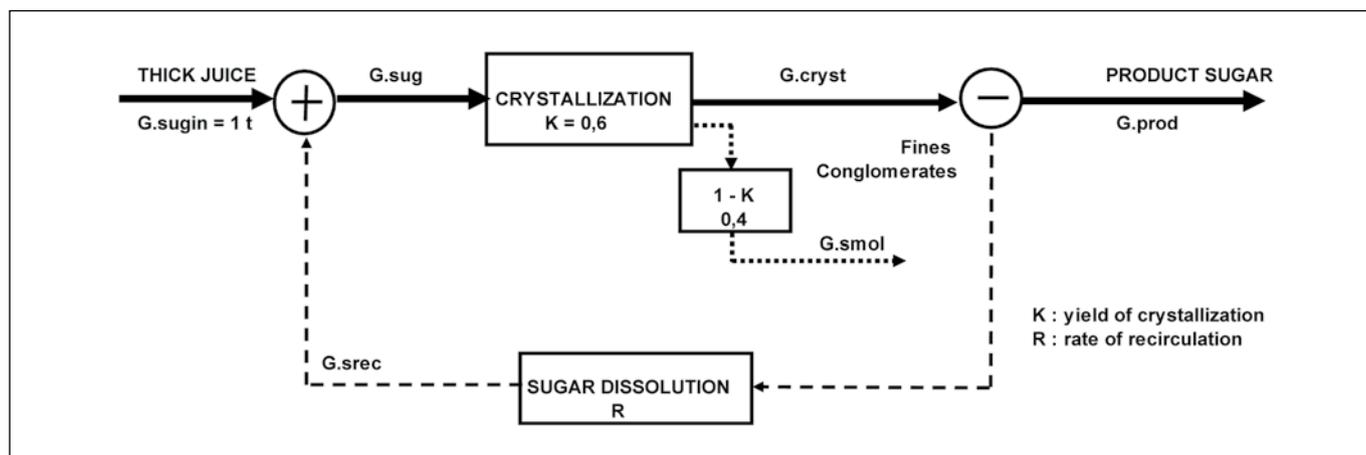


Table 3. The main massecuite and production parameters versus recirculation ratio R

R (%)	G.sug (t)	G.cryst (t)	G.smol (t)	G.srec (t)	G.prod (t)	Proc. cap (%)	Prod. yield (%)
0	1	0,6	0,4	0	0,6	100	60
10	1,063	0,638	0,425	0,063	0,575	106,3	54,1
20	1,137	0,682	0,455	0,136	0,545	110,7	47,9
30	1,220	0,732	0,488	0,220	0,512	122	42,0

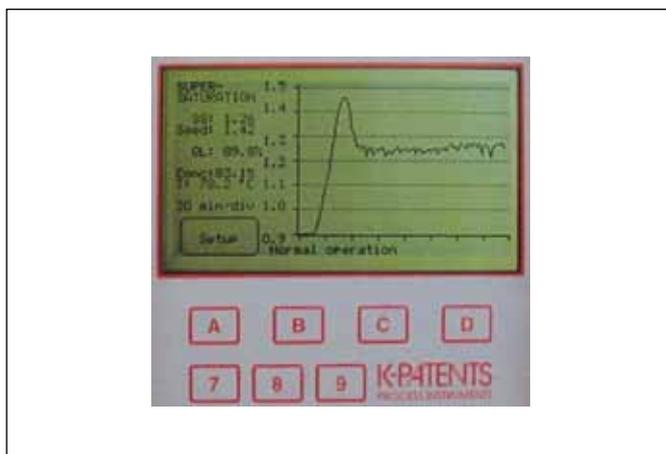
The role of supersaturation in crystallization

Crystal growth rate is proportional to supersaturation; it is therefore evident that it should be safely close, but below its high limit. This needs reliable on-line data on supersaturation and effective

Figure 3. The PR-01-S type K-PATENTS refractometer



Figure 4. SeedMaster display



control to implement this strategy all over the strike.

Excessive supersaturation is made responsible for the unwanted formation of fines and (with poor circulation) conglomerates as well. After centrifuging and screening they are dissolved and returned (“recycled”), only to be used again to feed the process of crystallization. This results in the increased use of water, energy and time and in a sharp decrease of the effective product yield (Rozsa 2008). Usually there is only scarce, if any information on the amount of “recycled” sugar, though it is an excellent indication on the quality of control.

In Figure 2 it is assumed that thick juice containing 1 t of sugar / Δt has to be processed by the pan farm (Δt is the time needed to produce the amount of thick juice containing 1 t of sugar) in order to maintain the smooth operation of the plant (juice extraction and processing is a continuous operation, while batch pans operate discontinuously). If the pan farm is not able to cope with this requirement, disturbances and delays will result. Table 3 lists appropriate data with different rates of recirculation, where R is the percentage of recycled already crystallized sugar. “Proc. cap” represents the processing capacity of the pan farm. In ideal case (R = 0%) the required processing capacity is 100% and product yield is 60% (crystallizing 1 t of sugar in the thick juice results in 0.6 t of perfect quality product). “G.smol” is the amount of sugar in the molasses.

If, however, the rate of recirculation is 20% for example, the processing capacity of the pan farm has to be increased by 10.7% to be able to cope with the thick juice production, and the product yield will drop to 47.9%. Besides that, more water and energy will be needed as well. “Pushing” the rate of crystallization by knowingly or unknowingly increasing supersaturation is contra productive indeed.

Besides the amount of “recycled” sugar crystal photos on the

Table 4. Important massecuite parameters and their on-line availability from the SeedMaster 2 device

Important parameters	SeedMaster 2
Supersaturation	Yes
Syrup and massecuite solids content	Yes
Crystal content	Yes
Mother liquor purity	Yes
Mean crystal size	Yes*
Syrup and mother liquor concentration	Yes

* If full seeding was practiced and there was no unwanted nucleation and dissolution.

product (samples taken directly after the sugar drier) can provide useful information on the control practice.

The SeedMaster instruments

The SeedMaster software option

It was proved that supersaturation is a multivariable function of several process parameters. It is a strictly liquid phase property. Its calculation needs - among others - fairly accurate on-line data on the concentration of the syrup / mother liquor during the complete strike. There is only one instrument, the process refractometer which can measure the liquid concentration selectively. It was therefore decided some time ago to select the PR-01-S type process refractometer, manufactured by K-PATENTS Oy, Finland as the basic instrument to provide concentration and temperature data (the refractive index depends on temperature, therefore it has to be measured

and used for compensation) for the on-line calculation of supersaturation. The refractometer readings are not disturbed by crystal content (selective measurement of liquid concentration), vapor or gas bubbles and color, and can provide the required accuracy (+/- 0.1%), so it proved to be an ideal tool to implement the on-line calculation of supersaturation. There is no need for extra hardware: the calculation is done by the optional SeedMaster software running in the computer of the process refractometer.

The main features of the SeedMaster software option are (Rozsa 1998):

- On-line calculation of supersaturation and mother liquor purity all over the strike.
- Display (numerical and trend) of the calculated data on the LCD of the instrument.
- Output of the calculated data as standard 4-20 mA output.
- Switch output to warn (lamp, horn) the operator to prepare the slurry for seeding.
- Automatic seeding of the vacuum pan based on supersaturation set point selected for seeding.

The display shown in Figure 4 comes from a refinery in Scandinavia. The trend shows typical shock seeding and supersaturation data quite above the high limit value. The ripples on the trend of supersaturation are due to intermittent syrup feed practiced in the refinery. The coefficient of variation (Cv) as reported by the laboratory was excellent, but above the

Figure 5. A possible SeedMaster 2 configuration

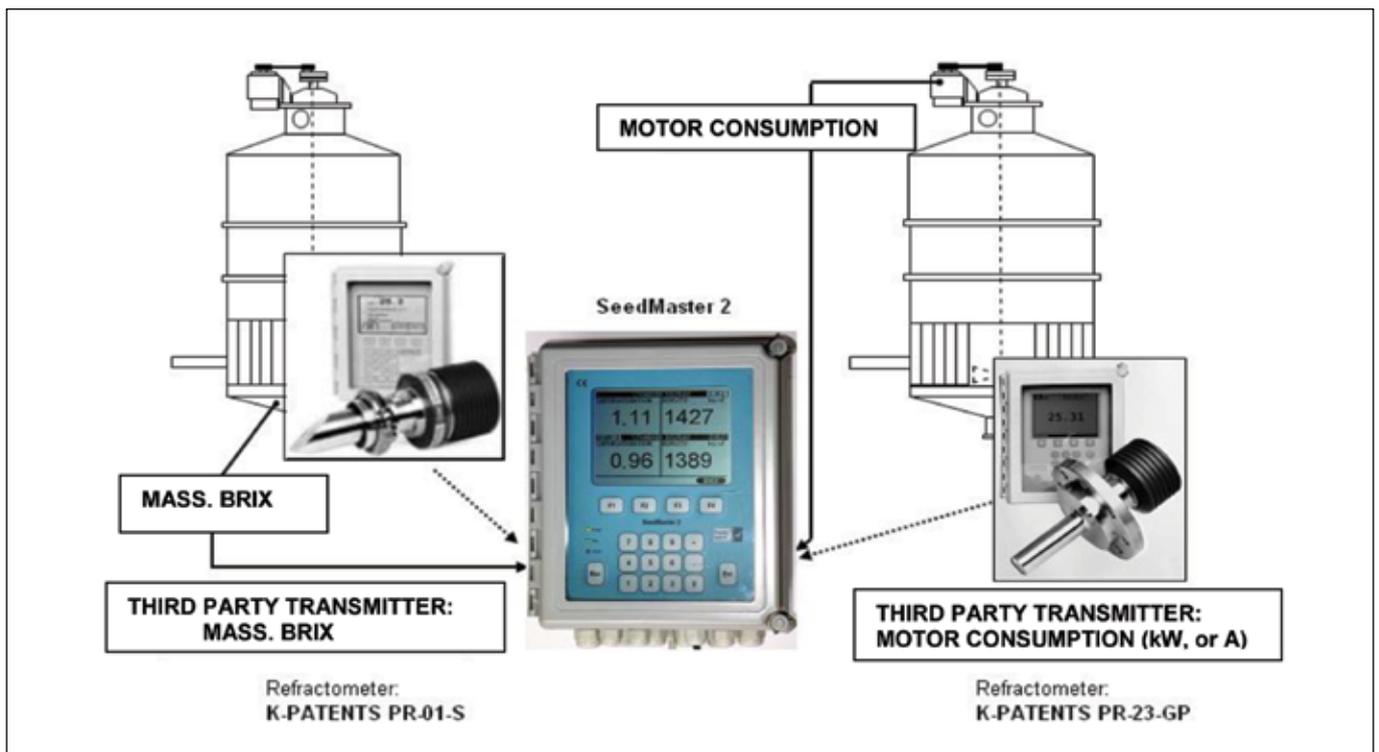


Figure 6. Some of the different display screens serving two vacuum pans

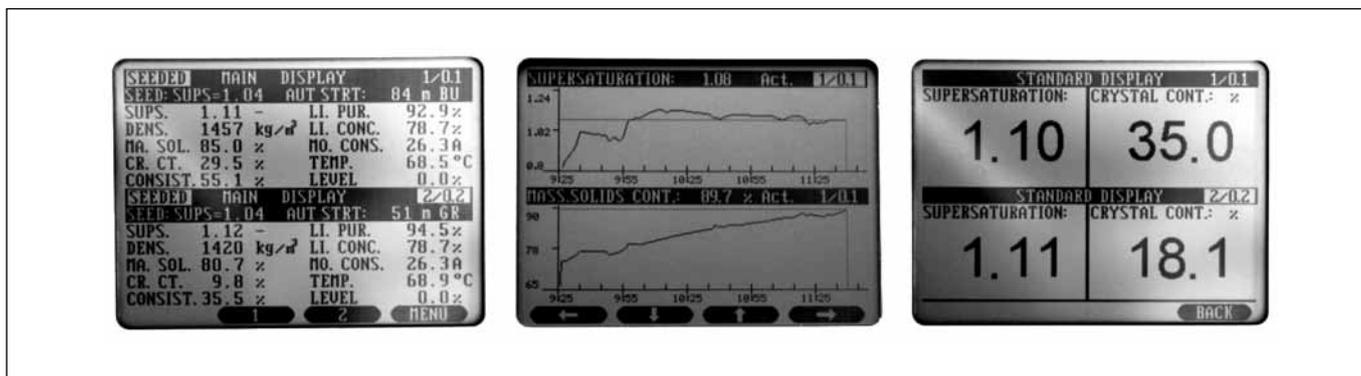


Figure 7. Monitoring supersaturation



limit supersaturation arose suspicion regarding product quality. Product crystal photos taken by a common digital camera had shown a large content of fairly similar size conglomerates. The plant manager was “shocked”.

The SeedMaster software has proved its worth in quite many applications in different countries of the world. PR-01-S type refractometers already in use can be easily upgraded by the software option, which is available from K-PATENTS.

The SeedMaster 2 device

Based on the valuable experience gained with the use of the SeedMaster software a new device, the SeedMaster 2 was developed (Rozsa 2006). The basic features of this instrument are:

- It has dedicated hardware.
- It can be used with any type of process refractometers manufactured by K-PATENTS.
- It can serve two vacuum pans simultaneously.
- Besides the concentration and temperature data received from the process refractometer(s), it relies on the use of a “3rd input” as well. It may come from any standard transmitter providing data on massecuite brix or density or stirrer motor power (current)

consumption (power is preferred).

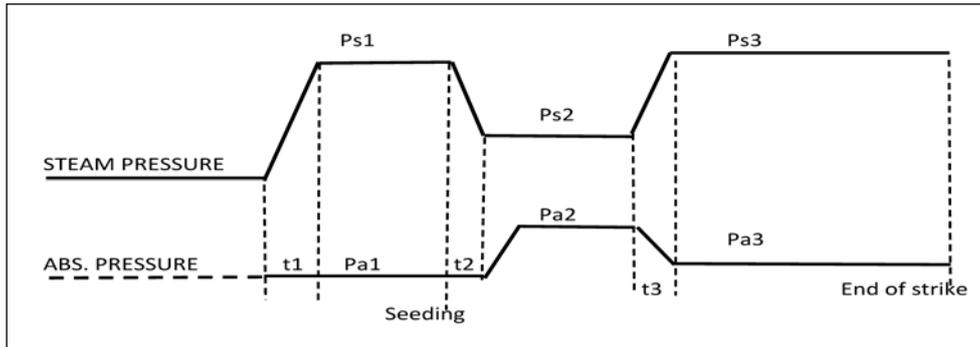
- Automatic seeding based on supersaturation.
- Outputs: 4 - 20 mA and Ethernet (Modbus TCP/IP).

Table 4 lists again the important massecuite parameters (see Table 1) and shows at the same time that on-line data on all of these parameters are available from the SeedMaster 2. This is due to the fact that more (three) on-line data are used for the calculations.

The SeedMaster 2 device has a large built-in data archive for 2 pans (Figure 5). All the measured and calculated data can be trended on its display for the actual (current) and for the three previous strikes. It is possible to show two trends of any of the available data simultaneously (for example: supersaturation and crystal content, Figure 6). Similarly, a condensed strike history archive is available for the actual and three previous strikes. When displayed, it lists supersaturation data when seeding, minimum, maximum and average values. These data provide important condensed information on the repeatability of strikes and eventual supersaturation limit excursions.

The SeedMaster 2 instrument is a “front end device”, and can be located right on the pan floor together with the K-PATENTS process refractometer. It is manufactured by Process Control

Figure 8. Steam and absolute pressure patterns characterizing the traditional “trial and error” method of pan control



Kft., Budapest, Hungary and is marketed by the manufacturer and K-PATENTS Oy, Finland.

Making effective use of supersaturation in strike control

Seeding

Seeding is a very important part of crystallization. There are two different methods in use to implement seeding in batch vacuum pans: shock and full seeding.

During shock seeding supersaturation exceeds the start of

nucleation limit ($SS > 1,15$) for some time, when with the addition of seeding crystals prepared in the slurry, formation of new crystals will take place. This is the time when the required number of crystals will be produced. Shock seeding is the traditional way of seeding, still practiced in many mills. It has, however, a basic problem: it is very difficult to control. The number of crystals formed during a time unit (1 minute, for example) increases very fast with increasing supersaturation

and depends on non-sugar content and composition as well. Nowadays shock seeding is mostly based on the measurement of a single parameter: syrup concentration. Figure 7 shows a monitor screen with the massecuite brix (measured by a microwave probe) and supersaturation (monitored by a SeedMaster 2 device) trends. It is evident from the supersaturation data that automatic shock seeding at exactly 80 Brix syrup concentration was practiced in this mill. It is also evident that this practice resulted:

- in quite different supersaturation readings in the seeding points ranging from as low as 1,10 to 1,26 (no wonder: supersaturation depends not only on liquid concentration), and

Know Your Brix.

Liquid and crystal sugar quality can be improved and production costs lowered by implementing in-line Brix measurements.

An economical solution, **K-Patents Process Refractometer PR-23** measures Brix and offers many opportunities for real-time process control. For instance, product flows can be adapted to the capacity of evaporators and separation columns, and automatic and accurate vacuum pan seeding can be performed. The supersaturation can be monitored over the complete strike.

K-Patents Process Refractometer PR-23 determines the Brix by making an optical measurement of the solution's refractive index. The fully digital technology, utilizing solid state CORE-optics and CCD-camera, provides an accurate and maintenance-free way to measure Brix.



- Full measurement range of 0-100 Brix • Accuracy +/- 0.1 Brix
- Automatic temperature compensation • CORE-optics: No drift, no re-calibration, no maintenance • Crystals, bubbles or colour have no effect on the measurement • Ethernet connection for remote operation.

K-PATENTS
PROCESS INSTRUMENTS

www.kpatents.com

K-Patents Oy
P.O. Box 77
FIN-01511 Vantaa, Finland
Tel.: Int.+358 207 291 570
Fax: Int.+358 207 291 577
E-mail: info@kpatents.com

K-Patents, Inc.
1804 Centre Point Circle, Suite 106
Naperville, IL 60563, USA
Tel.: (630) 955 1545
Fax: (630) 955 1585
E-mail: info@kpatents-usa.com



Figure 9. Supersaturation-governed cascade control of mother liquor concentration

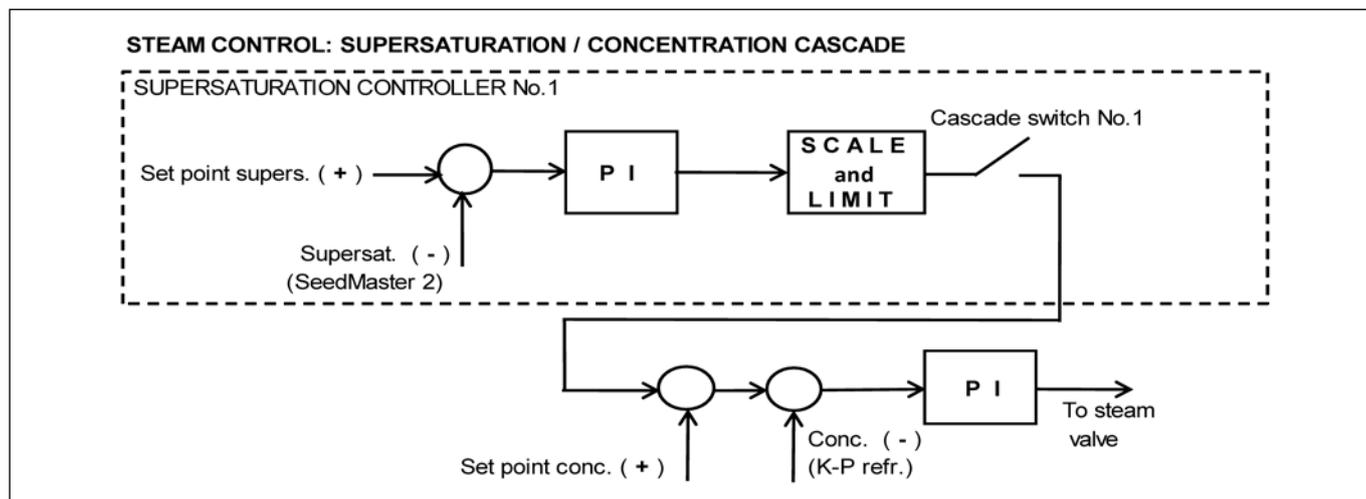
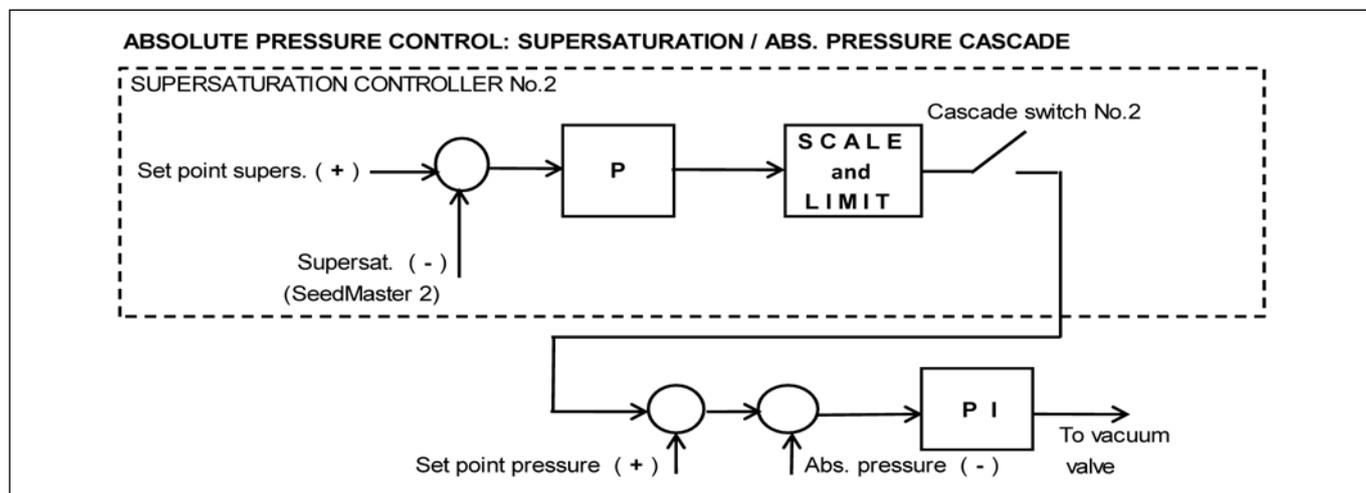


Figure 10. Supersaturation-governed cascade control of absolute pressure in the pan



• in considerable differences in the trends of supersaturation from strike to strike.

These differences certainly have their effect on mean crystal size, size distribution and conglomerate content as well. It is difficult to have constant product quality parameters with the shock seeding technique. (For more examples see Rozsa 2008, Part - 2).

Full seeding is the more advanced form of seeding. The basic idea is that the formation of new crystals (nucleation) should be prevented all over the strike. In ideal case the number of crystals when seeding and when dropping the charge should be the same and equal that of the seed crystals.

Full seeding can be implemented by:

- slurry, containing the required number of seed crystals, and
- footing magma.

Full seeding should be implemented in the 1.06 - 1.10 range of supersaturation, and it should be safely controlled later on during the complete strike within the 1.00 to 1.12 - 1.15 range.

It is to be noted that the use of slurry alone is no guarantee of full seeding; it is the supersaturation that really counts. If it

exceeds the nucleation limit, new crystals will be formed, the number of which is difficult to keep under control.

The more advanced way of full seeding is the use of footing magma to seed the pan. It is commonly prepared in two steps:

- first magma is produced in a cooling crystallizer; it is used to seed a normal pan to produce
- second magma, which is used to seed the product pans.

It is to be noted that consistent product quality can be achieved only by automatic seeding based on supersaturation.

Strike control

There are typically three control valves involved in crystallization control which control:

- feed syrup flow,
- absolute pressure (vacuum), and
- steam to the calandria.

All of the manipulated variables have a direct or indirect effect on supersaturation.

Controlling massecuite level (or volume)

This is a relatively easy problem which can be solved by a single PID control loop. There are two basic versions: the set-point for the controller can be massecuite level versus time, or level versus solids content (brix) measured by a microwave probe. In both cases it is preferred to have what we call a “loose” massecuite instead of a “tight” one because pan circulation is better in a major part of the strike and it is easier to supply the crystals with sugar.

Steam and absolute pressure (vacuum) control: The traditional method of control

Steam and absolute pressure control is quite often implemented by the use of dedicated single control loops with coordinated pressure set-points, similar to the ones shown in Figure 8. These can have different $P_{s1} \dots P_{sn}$ set-points for steam, $P_{a1} \dots P_{an}$ for absolute pressure and ramp times $t_{11} \dots t_{k}$. The actual numerical values are determined based on experience acquired during numerous strikes. This is what can be termed as a “trial and error method of strike control”.

The basic difficulties of this method are the followings:

1. It takes a lot of time, patience and experimentation to develop the appropriate pressure patterns for a single feed syrup. It took about 6 months to develop it in a refinery in Scandinavia. Plant managers are often reluctant to grant permission for this kind of long experiments.
2. It is very sensitive to changes in the process parameters, like feed syrup concentration and purity.
3. Real steam demand depends not only on feed syrup concentration, but on the rise (slope) of the massecuite level as well. Changes in the slope are only poorly reflected in these patterns.
4. Changes in the pressures and ramp times before seeding result in very profound changes in the number of crystals when shock seeding is practiced.
5. The set points depend on the sizes and construction details of the individual pans as well.

To sum up: The trial and error method of strike control can provide acceptable results only under very stable circumstances. If these cannot be assured, its development can become a never ending story.

Strike control based on supersaturation

Cascade control is characterized by the use of two control loops: the primary or master controller has the independent set point, while the output of the secondary controller manipulates the control valve. The set point of the secondary controller is modified by the output of the master controller. There are several advantages of cascade control. Without going into the details: disturbances arising in the secondary loop can be corrected by the secondary controller before they influence the primary variable. The current proposal is based on the use of cascade control.

Supersaturation is a function of several variables (see

Equation 2). The strongest effect comes from the syrup / mother liquor concentration, which can be directly measured by the process refractometer. It is straightforward to control syrup / mother liquor concentration in a secondary control loop, which manipulates the steam control valve (Figure 9). It receives on-line concentration data from the K-PATENTS process refractometer. Disturbances in liquid concentration will be corrected right by this secondary controller. The master controller is responsible to control supersaturation according to its set point by modifying the set point of the secondary controller accordingly.

It is temperature that - after liquid concentration - has the second largest effect on supersaturation. It can be directly influenced by the absolute pressure (vacuum) in the pan. Therefore, if it is possible to control absolute pressure (it is relatively easy to do so with pans served by individual vacuum systems), it is advisable to use a second cascade control configuration. The secondary controller in this case is the (already existing) pressure controller. Its set point should be modified by a second master supersaturation controller (Figure 10).

In cascade control the secondary controllers can be operated separately, that is without being influenced by their master controllers. In this case the “cascade switch” (implemented in the control software) is open. Real control of the primary variable (in our case: supersaturation) requires the closure of the cascade switch. This should be done so as not to disturb abruptly the operation of the secondary controller. Modern control systems have this “bumpless transfer” feature.

Computer simulation of strike control

Development of the trial and error method of strike control requires a lot of time. Changes made during one strike often are not successful, but it will turn out only hours later. Some parameters can be more or less different in the next strike which makes the “fine tuning” of the control solution difficult.

In order to avoid the problems associated with testing control designs on the real pans, a vacuum pan simulation program was developed. It relies:

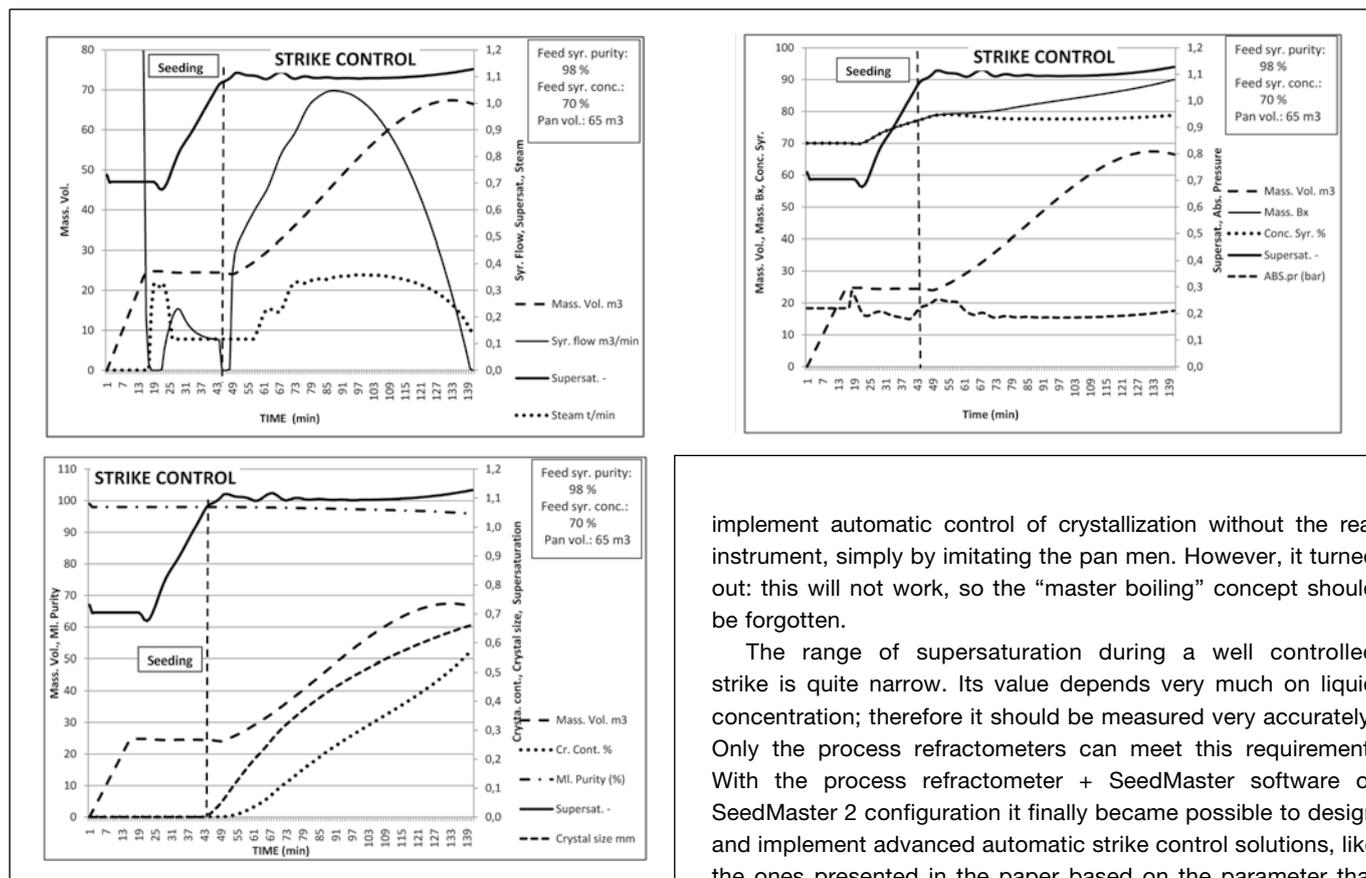
- on material and energy balances,
- crystal growth rate calculation and
- on the use of actual dead time and time lag data observed during monitoring a large number of strikes in different mills.

The simulation is made complete with the addition of the level and cascade controllers required to study the operation of a proposed complete strike control design. Different parameters of crystallization (for example: feed syrup concentration, purity and quality) can be changed easily. Due to its flexibility, a new “strike” with new parameters can be run within a few minutes. The main task was to implement full seeding and keep supersaturation under control meeting the requirements as discussed before.

Besides the steam and syrup flow data Figure 11 shows all of the important massecuite parameters as well. It is to be noted that there is no need to measure feed syrup and steam flow when implementing the control design on a real pan.

All of the important massecuite parameters are available from the SeedMaster 2 during a real strike.

Figure 11. Trends of the main massecuite parameters during a simulated strike



implement automatic control of crystallization without the real instrument, simply by imitating the pan men. However, it turned out: this will not work, so the “master boiling” concept should be forgotten.

The range of supersaturation during a well controlled strike is quite narrow. Its value depends very much on liquid concentration; therefore it should be measured very accurately. Only the process refractometers can meet this requirement. With the process refractometer + SeedMaster software or SeedMaster 2 configuration it finally became possible to design and implement advanced automatic strike control solutions, like the ones presented in the paper based on the parameter that really counts: supersaturation.

The important data on the simulated strike are listed in Table 5.

The strike control strategy discussed above is one of the several possible ones. There can be other designs as well, but all of them should rely on the use of on-line data on supersaturation.

Conclusions

Supersaturation cannot be measured by any single instrument. Consequently, sugar crystallization without real on-line information on it is based on pure guesswork. The consequences of this lack of important on-line information and the lack of its use in advanced control may result in less than acceptable product quality, repeatability and profitability. Supersaturation is just a too important parameter to be left neglected, or being satisfied with paying only lip service to it.

The SeedMaster Instruments have been developed to fill the need long felt by process control practitioners serving the sugar industry. They felt irritated when they were told to

References

Radford, D.J. and Cox, M.G.S. (1986) The use of electrical properties measured at radio frequencies for pan boiling and brix control. *Zuckerind.* 111: 922-930.

Saska, M. (2002) Boling point elevation of technical sugarcane solutions and its use in automatic pan boiling. *International Sugar Journal* 104(1247): 500-507.

Rozsa, L. (1997) Sensor performance in monitoring supersaturation. *International Sugar Journal* 99(1182): 263-268.

Rozsa, L. (1998) The SeedMaster device for on-line supersaturation measurement and automatic crystallizer seeding. *International Sugar Journal* 100(1200): 601-607.

Rozsa, L. (2000) Sucrose solubility in impure cane sugar solutions. *International Sugar Journal* 102(1217): 230-235.

Rozsa, L. (2003) Sensor selection: Still an issue in sugar crystallization control. *Proc. Philippine Sugar Technologist's Convention*, Bacolod City, Philippines: 139-152.

Rozsa, L. (2006) SeedMaster 2: A universal crystallization transmitter and automatic seeding device. *International Sugar Journal* 108(1296): 683-695.

Rozsa, L. (2008) Sugar crystallization: Look for the devil in the details - Part 1. *International Sugar Journal* 110(1316): 403-413.

Rozsa, L. (2008) Sugar crystallization: Look for the devil in the details - Part 2. *International Sugar Journal* 110(1320):729-739.

Table 5. Important parameters of a simulated strike

	Seeding	Maximum	Minimum	Average
Supersaturation	1.07	1.12	1.07	1.10
Feed syrup purity (%)	Crystal content (% vol.)	Crystal size (mm)	Mass. vol. (m³)	Mass. solids cont. (%)
98	53	0.66	65	90