Seed-cooling crystalliser technology for improvement of crystal quality and sugar recovery

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Abstract
Sugar recovery and crystal quality are two important plant performance aspects. Usually, slurry, dry seed or sugar magma are employed as seed material for the main product pans. Another possibility is developing a seed material of about 60-120 µm grain size as an intermediate product concerning crystal size between slurry and a typical A footing massecuite with 320-420 µm crystal size. Instead of achieving crystal growth by evaporation/concentration the same can be achieved by cooling. This is the basis of the seed-cooling crystalliser technology. The seed-cooling crystalliser system has a series of advantages including: increased sugar recovery by reduction of C molasses purity; improved crystal quality; improved crystal colour; reduced seed development time and increased strike speed; increased crystal size for B and C massecuite. The seed-cooling crystalliser system and the achievable benefits are described. The technology is widely used in the beet sugar industry but there is only little experience as yet in the cane sugar industry. However, the principles of operation are similar and seed-cooling technology can clearly allow achieving a better sugar quality and improved sugar recovery.

Key words
Pan automation, crystallisation, sugar recovery, crystal quality, seed cooling crystallisation

INTRODUCTION
All sugar factories operate their boiling house with similar targets, such as the production of sugar of a specified quality and crystal size and size distribution with minimum conglomerates and free of fines, optimal molasses exhaustion and low sugar losses, as well as better sugar recovery at various process stages. To attain these aims, the operations prior to crystallisation must be carried out properly to obtain a smooth crystallisation progression in accordance with the established crystallisation scheme.

In the cane sugar industry, almost every sugar factory has classical crystal-graining pans for the preparation of seed for the massecuite strike pans. Usually the seed prepared in the graining pans lacks consistency, yet the quality of the seed material influences considerably the sugar quality of the final product and the sugar recovery.

In order to optimise the pan station and to improve the sugar quality, seed-cooling crystallisation (SCC) technology is used to produce uniform seed magma for the massecuite pans in the beet sugar industry (Neumann 1988; Schiweck et al. 1987; van der Poel et al. 1998). In the cane sugar industry, Broadfoot and Hutchinson (1980) investigated the development of continuous seed-cooling crystallisation systems but this did not succeed. The seed-cooling crystalliser system described here is based on batch technology and is common in the beet sugar industry. The seed-cooling crystallisation is an add-on technology for the classical crystal-graining pan system used in the cane sugar industry. Apart from the sugar quality improvement, the application of seed-cooling crystalliser technology can improve sugar recovery at the pan station.

CONVENTIONAL METHOD OF SEED MAGMA PREPARATION
In almost every cane sugar factory, the seed magma is prepared in a batch pan by slurry or from sugar dry seed coming back from the sugar-handling section. The initial filling of the pan is done with higher purity feed material (syrup or mixture of syrup and A molasses depending on the massecuite to be prepared from the grain). Once the required supersaturation level is achieved in the pan after the concentration of the initially filled feed material, slurry or dry seed magma is added to the pan as seed material. Afterwards, the pan-boiling process proceeds further for crystal growth.
PROBLEMS IN THE SEED MAGMA PREPARATION WITH CONVENTIONAL METHODS

Usually crystal slurry or dry seed is used to prepare the seed magma in the graining pan. Preparing seed magma with both materials has some problems in achieving a uniform crystal size that is free from conglomerates.

Conventional vacuum pan crystallisation with slurry is difficult to handle during the crystal development phase. After the addition of slurry and if a high evaporation velocity exists, the crystal surface is often too small to crystallise the excessive supply of sucrose in the oversaturated solution without forming secondary grain and conglomerates. In order to use slurry as seed material, very careful supersaturation management is required, which is often difficult to achieve in the case of evaporation crystallisation without experienced operators in control. Substantial conglomeration or dissolution of the added slurry crystals may occur.

The time frame after reaching the required supersaturation level for seeding (Fig. 1) is usually the most critical period especially regarding slurry strikes. Time is required for seed development as the initial slurry crystal size varies in a range of 5-15 µm and the supersaturation remains at a higher level. Once sufficient crystal surface is available, the operation becomes less critical and the supersaturation will reduce faster as more crystal surface becomes available for crystallisation.

![Fig. 1. Level, supersaturation and crystal content development during a slurry strike.](image)

The B and C graining pans are usually seeded with 5-15 µm seed, which is very vulnerable to dissolution and conglomeration in batch vacuum pans, and can lead to poor pan performance and, in consequence, often to lower recovery.

For A massecuite pans, dry reject seed crystals from the sugar handling section is often used as the seed material for graining pans in cane sugar factories. Usually the quality of the dry seed coming back from the sugar screening is not consistent and often the crystals have a poor coefficient of variation (CV). After seeding the batch vacuum pan with dry seed magma, the pan operators are used to adding water to dissolve the smaller crystals with a size less than 50 µm. Additional water for crystal dissolution in the batch vacuum pans has a negative effect on the process energy economy, as the added water has to be evaporated later.

Many cane sugar factories have no automation or inadequate automation installed on the batch vacuum pans. Due to the lack of an automation system the pan operators control pan operation based solely on their experience. Usually they face many operational issues, including loss of control of the supersaturation. Due to process variations, even when a very good pan control automation system is installed, supersaturation management is sometimes not easy. A pre-requisite for the introduction of the SCC technology is proper pan automation (Morgenroth et al. 2013).
SIGNIFICANCE OF SEED MAGMA QUALITY PARAMETERS

The quality of the final crystals depends very much on the coefficient of variation of the crystals in the seed magma (Fig. 2; Rein et al. 1985). This emphasises the need to prepare seed magma of good quality.

In order to achieve a better product quality, seed magma has to meet certain quality parameters, such as:

- Good crystal size distribution;
- Reasonable crystal content to reduce the quantity of seed material;
- Low conglomerate content; and
- The seed crystals should have sufficient size to survive the initial period in the pan after seeding.

The uniformity in the crystal size distribution improves the centrifugal performance. In case of a bad coefficient of variation (CV), smaller crystals fill the gaps between the larger crystals, resulting in a layer of crystals in the centrifugal, which do not purge properly and small crystals can also pass through the screen which leads to a lower molasses exhaustion.

Crystal size distribution is generally characterised by the coefficient of variation (CV), which is defined as:

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CV = 100 \times \frac{\sigma}{dm}
\]

where \(dm\) = mean crystal size; \(\sigma\) = standard deviation of size distribution.

In a high grade boiling, a CV of 30-34% is acceptable and a limit on the quantity of fines around 3-5% is usually accepted.

SEED MAGMA PREPARATION BY COOLING CRYSTALLISATION

Seed-cooling crystallisation has been used successfully in the beet sugar industry for decades (Neumann 1988). With seed-cooling crystallisation, the required quality parameters for the seed magma can be achieved easier than in evaporative crystallisation.

In case of seed-cooling crystallisation, the conditions required for the initial development of the crystals can be controlled better than during the evapo-crystallisation. In this case, seed-cooling crystallisation is used as a first step for the crystal development followed by evapo-crystallisation as the second step for the crystal development.

In the first step (cooling crystallisation), slurry particles with an average diameter (d50) of approximately 5-15 \(\mu\)m develop up to a crystal size d50 of about 60-120 \(\mu\)m at a crystal content of 20-25%. Syrup or liquor is used as the feed solution.
In the second step (evapo-crystallisation), the crystal formed in the seed cooling crystalliser is used as seed in the A batch vacuum pan to grow the crystals up to a diameter d50 of approximately 220 µm and in a subsequent strike to 380 µm, before being used as seed material for the final A product pans that achieve a diameter d50 of about 620 µm crystal size.

For B and C massecuite, seed magma from step 1 of the seed-cooling crystallisation can be used directly in the normal seed pans. Cane sugar factories using some boiling schemes will operate with relatively small crystal sizes in the B and C massecuites in order to offer enough crystal surface for proper supersaturation and crystal growth control. With better automation and considering sufficient residence time, the crystal size can be increased to some extent for the final massecuites in order to allow for easier centrifugation work. A typical crystal size development for B massecuite would start at 60 µm for first-stage seed magma, followed by 150 µm for B seed magma, and a final crystal size for B massecuite of 250 µm. A typical crystal size development for C massecuite would start at 60 µm first-stage seed magma, followed by 100 µm for C seed magma and a final crystal size for C massecuite of 160 µm.

**SEED-COOLING CRYSTALLISER OPERATION**

The process setup of a seed cooling crystalliser system (Fig. 3) includes:

- Slurry production and processing;
- Seed1 unit (seed cooling crystalliser);
- Strike receiver for Seed 1;
- Seed2 pan (vacuum pan); and
- Strike receiver for Seed 2.

![Fig. 3. Seed-cooling crystalliser (SCC) arrangement.](image)

The slurry can either be purchased or can be prepared in the factory. Slurry is usually a mixture of isopropanol alcohol and sugar that is ground in ball mills (rotating drums containing steel balls or rods). A typical proportion of ingredients for an 8 L mill is: 6.4 L of isopropanol alcohol and 2.7 kg of white sugar. The median grain size of the added sugar should not be above 1 mm. The duration of one grinding is about 4 h. The produced slurry can be stored in rotating cylindrical air sealed
bins with a capacity of approximately 50 L. On demand, the slurry and glycerine are mixed. Glycerine should ensure a good distribution of the slurry during injection. The glycerine, which is mixed with the slurry, has to be saturated with sucrose by adding large crystals with constant movement of the bin to maintain a saturated condition. If not saturated, slurry particles will dissolve in the glycerine.

The slurry bin is installed directly at the top of the seed-cooling crystalliser. The required slurry mixture has to be added to the bin just before usage in order to avoid any dilution because of the high hygroscopic nature of the mixture.

The seed-cooling crystalliser is a vertical cylindrical tank (Fig. 4) equipped with a high performance stirrer. It has to be connected to the vacuum system and to the heating and cooling circuit. The heating and cooling circuit includes one heater which can either be operated with steam for heating or cold water for cooling. The seed-cooling crystalliser needs to be very well automated. A temperature control is required throughout the strike to achieve a 6-8 K temperature difference between the material in the crystalliser and the cooling water. With good automation and good control on the temperature, a suitable environment to the seed particles for the initial development can be provided. It is recommended to use high accuracy field transmitters.

At the beginning of the batch, the SCC is filled with hot syrup which is concentrated to achieve 78-80% dry substance. After achieving a Brix of 78-80%, the syrup is cooled down to a supersaturation coefficient of about 1.08 before the slurry is added without taking too much cold air into the cooling crystalliser. The cold air in the crystalliser could lead to secondary nucleation.

The process of slow cooling proceeds until the temperature reaches about 35°C. At this point, a seed magma of size 60-120 µm is achieved. Afterwards the seed magma from the seed cooling crystalliser is discharged into the strike receiver. The seed-cooling crystalliser can be cleaned by steaming out. Then it is available for the start of a new batch.

The third part of the system consists of a batch vacuum pan where seed magma from the seed cooling crystalliser is used as seed. As the crystal size of the seed magma is already more than 60-100 µm, it is much less vulnerable to the high evaporation velocity compared to slurry seeding.
The seed 2 magma prepared in the batch vacuum pan is then discharged into the strike receiver and is further used as seed in the A product pans.

The second step of seed magma preparation is often considered for the A massecuite boiling. While for the B and especially for C massecuite boiling, the seed magma from the seed-cooling crystalliser (first step) can be directly fed into the product pans. In case of continuous pans, a second step of seed magma preparation is always required.

First experiences with seed-cooling crystalliser technology will be gained in Indian and Pakistan sugar factories where they have been installed or are under installation. Results will be reported once available.

**REDUCTION IN PAN STRIKE TIME**

Instead of adding 5-15 µm slurry, adding crystals of 60-120 µm reduces the strike time of the graining pans. For slurry strikes, a longer homogenisation period is required after the slurry addition to the pans while adding already developed grain as seed to the pans cuts short the homogenisation time by 10-15 min.

With the conventional method of seed magma preparation, the crystal uniformity is lower in comparison to the seed magma crystals prepared with the seed cooling crystallisation technology. When adding non-uniform crystals as seed in the pans, water is required to wash the smaller crystals in order to improve the CV, causing drawbacks in energy economy.

**IMPROVEMENT IN SUGAR RECOVERY AND CRYSTAL QUALITY**

With the implementation of the seed-cooling crystalliser technology, improvement in the sugar recovery can be achieved. Obviously a better CV value for A, B and C sugar allows a better centrifugal performance and reduction in molasses purities and consequently a better molasses exhaustion. Less conglomerates and a good CV also allow for a reduction of sugar colour resulting in less water requirement for washing in the centrifugals.

As shown in Figure 2, the final crystal quality depends on the crystal quality of the seed magma. The product crystal quality usually improves with the improvement in the crystal quality of seed magma. Due to the uniform crystals, sugar losses at the centrifugals can be reduced and the amount of fine crystals recycled back from the sugar screening also reduces. It indirectly optimises the plant efficiency as well as the pan station capacity.

One other important benefit for C massecuite is achieved by introducing a relatively small amount of seed massecuite to the C graining pan. Normally a seed purity of 70-74% is targeted here for seeding in order to ensure a proper crystal development. This can usually only be achieved by mixing syrup and A molasses and filling the calandria of the C seed pan up to the calandria top. A larger volume of higher purity material can limit the final molasses exhaustion. The amount of seed magma from the seed cooling crystalliser system is proportionally smaller and allows reducing the C massecuite purity. This procedure is standard practice in many beet sugar factories and also some sugar refineries.

The reduction of C massecuite purity which is possible with the seed-cooling crystalliser can increase the sugar output of a 12 000 t cane/day cane sugar factory with about 14% Pol in cane by about 6900 t/year, resulting in €1.5 million additional income at 180 days of operation and a sugar price of €215/t sugar.

**SUMMARY**

Proven in the beet sugar industry for decades, seed-cooling crystallisation technology can be implemented in the cane sugar industry as well for sugar quality and sugar recovery improvement. Due to the better uniformity of the crystal grain, sugar crystal quality and crystal colour can be improved. The higher crystal uniformity (CV) also allows for better centrifugal performance and therefore a lower crystal loss and smaller purity rise between mother liquor and molasses at the centrifugals, resulting in a better final molasses exhaustion.

Use of the seed magma from the seed cooling crystalliser helps reduce the purity levels in the B and especially C massecuite pans.

There is also a good potential to optimise the boiling house performance, as well as the plant performance with the implementation and proper operation of seed-cooling crystallisation technology.
Technologia de cristalizador por enfriamiento de semillas para mejorar la calidad del cristal y recuperación de azúcar

Resumen. La recuperación de azúcar y la calidad del cristal son dos aspectos importantes del desempeño de una planta. Usualmente, lechada, semillas secas o azúcar magma son empleados como semillas para los principales productos en tachos de coccimiento. Otra posibilidad es desarrollar semillas de alrededor de 60-120 µm de tamaño de grano como un producto intermedio en relación con el tamaño de cristal entre lechada y un típico pié de masa cocida A con un cristal de 320-420 µm de tamaño. En vez de lograr un crecimiento del cristal por evaporación / concentración, puede hacerse por enfriamiento. Esto es la base de la tecnología del cristalizador por enfriamiento de semillas. Este sistema tiene una serie de ventajas que incluyen: aumento de la recuperación de azúcar por disminución de la pureza de la melaza C, mejora de la calidad del cristal, mejora en el color del cristal, reducción del tiempo de desarrollo de semillas y aumento de la velocidad de templado; aumento del tamaño de cristales de las masas cocidas B y C. Se describe el sistema de cristalizador con enfriamiento de semillas y los beneficios alcanzables. Esta tecnología es ampliamente usada en la industria de azúcar de remolacha, pero aún hay poca experiencia en la industria azucarera de caña. Sin embargo, los principios de operación son similares y la tecnología de enfriamiento de semilla puede claramente lograr una mejor calidad de azúcar y mejorar la recuperación.

Palabras clave: Automatización de tachos, cristalización, recuperación de azúcar, calidad del cristal, cristalización por enfriamiento de semillas