

Energy and cost efficiency in the sugar house: combining proven methods with continuous crystallization and vapor recompression

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Abstract: Energy input in the sugar house is a key factor in the overall energy requirement of the sugar manufacture in a beet sugar factory. The amount of water introduced via the thick juice and the quantity of wash water used in the centrifugals are crucial indicators of the steam requirement in the sugar house. Standard methods for reducing the steam requirement are, however, of limited use in practical applications. Moreover, changes in the political and economic framework call for concepts with an enhanced energy and cost efficiency in the sugar house. By combining continuous crystallization with mechanical vapor recompression, the

energy requirement can be significantly reduced. In crystallization, the temperature difference between the heating steam and the vapor has to be kept low, which makes the VKT with minimum energy input particularly suitable for this process. This paper presents custom strategies for a VKT with this plant configuration, specifically regarding plant and equipment design and operation.

Keywords: sugar manufacture, overall energy requirement, continuous crystallization, vapor recompression

1 Introduction

A new age is about to begin for European beet sugar factories. The European Climate Law [1] has set binding guidelines applicable within Europe for the reduction of greenhouse gases (“European Green Deal”). As a first target, the European community has been called upon to reduce net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels; the second target to be reached by 2050 is to achieve full climate neutrality across the EU. Naturally, both these targets also apply to the sugar industry.

These binding targets necessitate considerable changes in sugar manufacture, and huge efforts will be required to implement the corresponding measures. A major step towards decarbonisation is the general electrification of thermal processes in sugar manufacture; this will then be combined with the procurement of electrical energy from renewable sources in a further step [2, 3].

Driven by high costs for primary energy, European beet sugar factories in particular have always strived to produce sugar with a low energy input. This means that they are experienced in applying energy-saving measures. The current political approach, however, requires measures beyond this, which thus far have been unable to be economically applied. This paper will focus on the energy demand of the sugar house, which utilizes the largest proportion of the vapors from the evaporator station. Decisive parameters for steam consumption include the water intake via the thick juice and

the demand for dissolving media for B and C sugar, as well as the amount of wash water used in the centrifugals.

A range of concepts have for several decades been used in crystallization to automate the process, thus making it to a large extent reproducible. Depending on the crystal size aimed for, one- or two-stage seeding processes are often applied. They primarily serve to ensure that the feed solution has the maximum dry substance content. Thanks to the process design, the water intake and thus the steam demand are reduced to a minimum.

The application of continuous crystallization – characterized by a steady steam demand with a low difference in pressure between the heating steam and the vapors – plays a decisive role. This especially applies to concepts with mechanical vapor recompression, where the input of thermal energy (steam) to the sugar house can be replaced by electrical energy.

2 Conventional measures to save steam in the sugar house

Various measures for saving energy in sugar factories are being applied in the sugar house. To compare the energy-sav-

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ing measures, a conventional state-of-the-art sugar house scheme showing four products has been used as a basis – see Figure 1. From thick juice with a dry substance content of 74%, refined sugar (WZ1), white sugar (WZ2), and molasses are produced. In an example calculation with this set-up, the sugar house needs a steam quantity of 10.2 kg/100 kg beet (with a sugar content of 17.5% in the cossettes), which corresponds to a thermal energy demand of 437 kWh_{th}/t sugar. For running electrical equipment such as pumps, agitators and centrifugals, an additional amount of approx. 36 kWh_{el}/t sugar is required (based on [4]).

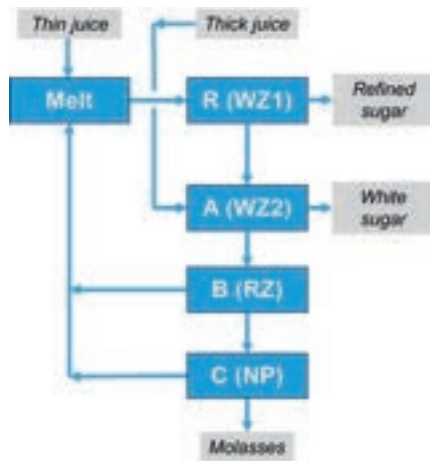


Fig. 1: 4-product crystallization scheme as a basis for calculating the energy demand of a sugar house

The thermal energy demand (heat) is largely determined by water evaporation during crystallization, corresponding to the amount of water added to the crystallization process:

- Water in the added thick juice
- Wash water and screen washing on the centrifugals
- Water in thin juice used for dissolving B and C sugar
- Water for diluting the massecuite during crystallization (strike holding, rinsing etc.)
- Hot water for cleaning, if it is recycled into the process

Within this list, the dry substance content of the thick juice has the greatest influence on the heating steam demand of the sugar house. By way of example, Table 1 shows the effects on the heating steam demand when the dry substance content of the thick juice changes.

On average, a 2% increase in the thick juice dry substance content leads to a reduction in the heating steam demand for the sugar house by around 0.7 kg/100 kg beet. It should

Table 1: Heating steam demand for the sugar house as a function of the dry substance content of the thick juice; with the corresponding quantity of water evaporation in the evaporator station

Thick juice Dry substance content in %	Steam demand for the sugar house in kg/100 kg b.	Water evaporation in the evaporator station in kg/100 kg b.*
68.0	12.36	77.74
70.0	11.60	78.47
72.0	10.88	79.16
74.0	10.20	79.80
76.0	9.55	80.42

* Thin juice: 16.65% dry substance content.

be mentioned here that the saved water evaporation in the sugar house must be balanced by an equally increased level of water evaporation in the evaporator station (Table 1). Thanks to the multi-effect evaporation, the lower boiling point elevation, and a better heat transfer coefficient in the evaporators, this additional water evaporation can be realised with less effort there, thus contributing to an overall reduction in the energy demand for the sugar factory.

Further standard energy-saving measures, such as optimising the application of water at the centrifugals or avoiding the addition of water in the strike holding phase, have already been considered in the specified energy consumption for this design example of a sugar house with a 4-product crystallization scheme. The production of syrup from B and C sugar using thick juice instead of thin juice is, however, not possible for this basic crystallization scheme that produces refined sugar from B and C sugar.

To achieve the targeted reduction in CO₂ emissions from sugar production, conventional measures can only contribute to a limited extent [5]. A further reduction in the energy demand can only be realised using measures beyond the ones described above, e.g. by utilising mechanical vapor recompression in the sugar house.

3 Continuous crystallization and mechanical vapor recompression

Mechanical vapor recompression is widely applied in industries that use evaporation and drying processes (e.g. breweries, dairies, seawater desalination, salt production, chemical industry) [6]. Like heat pumps, this technology utilizes the principle of raising a heat flow from a low temperature level to a higher temperature level. Mechanical vapor recompression combined with crystallization in sugar production has been applied since 1946 in a Swiss sugar factory [7] and can be considered a technically mature process.

3.1 Specific energy requirements of evaporating crystallizers

The energy demand for mechanical vapor recompression is determined by the pressure ratio of supply pressure to suction pressure, by the isentropic efficiency, and by the mechanical/electrical efficiency of the driving engine (normally, either an electric motor with frequency converter or an electric motor with gear stages). Suppliers of vapor blowers and turbo compressors are working to optimise the individual efficiencies, aiming to achieve the best economically justifiable overall efficiency. For the following comparison, a value of 0.81 is applied as default value for the efficiency of a recompression stage, which results from an isentropic efficiency of 0.90 and a mechanical/electrical efficiency of 0.90.

To estimate the electrical energy demand per ton of vapors sucked in (specific electrical energy demand), different types of evaporating crystallizers are compared in combination with mechanical vapor recompression. All crystallizer types

are operated with a vapor pressure of 0.20 bar abs. The heating steam pressure needs to be adapted according to their design: Batch evaporating crystallizers can be operated with 1.00 bar abs in white sugar crystallization, while continuous evaporating crystallizers without agitators to support the massecuite circulation can be operated with 0.85 bar abs [8], and with 0.70 bar abs for a vertical continuous evaporating crystallizer (VKT) [9] that is equipped with agitators. The specific electrical energy demand for vapor recompression resulting from the calculation shows clear differences (Fig. 2): In the example calculation, the plant with continuous crystallization VKT needs 25% less electrical energy than the plant with batch evaporating crystallizers. Continuous evaporating crystallizers (CVP) without agitators for massecuite circulation have an energy demand for vapor recom-

pression that ranges between those of the two evaporating crystallizer types stated before. Moreover, for lower pressure increases, fewer stages are needed for vapor recompression, which additionally saves investment costs for the compressors to be installed.

3.2 Energy study for a sugar house with VKT and mechanical vapor recompression

In an energy study, the sugar house described above is supplemented by a three-stage mechanical vapor recompression unit (MVR). The compressed vapors are used for heating the VKTs for A and B product (Fig. 3). For C product crystalliza-

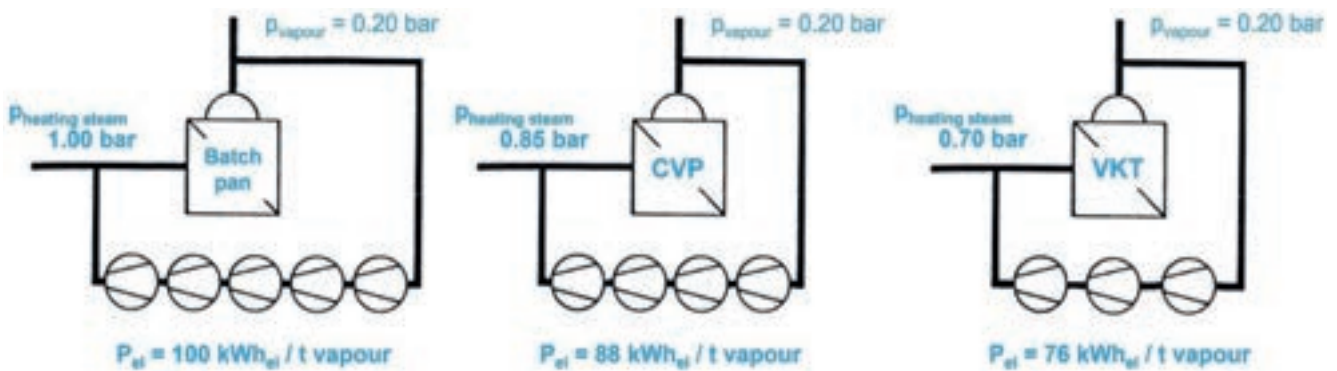


Fig. 2: Different types of evaporating crystallizers with vapor blowers as vapor compressors in a simplified scheme; with the calculated specific energy demand in kWh/t of compressed vapors

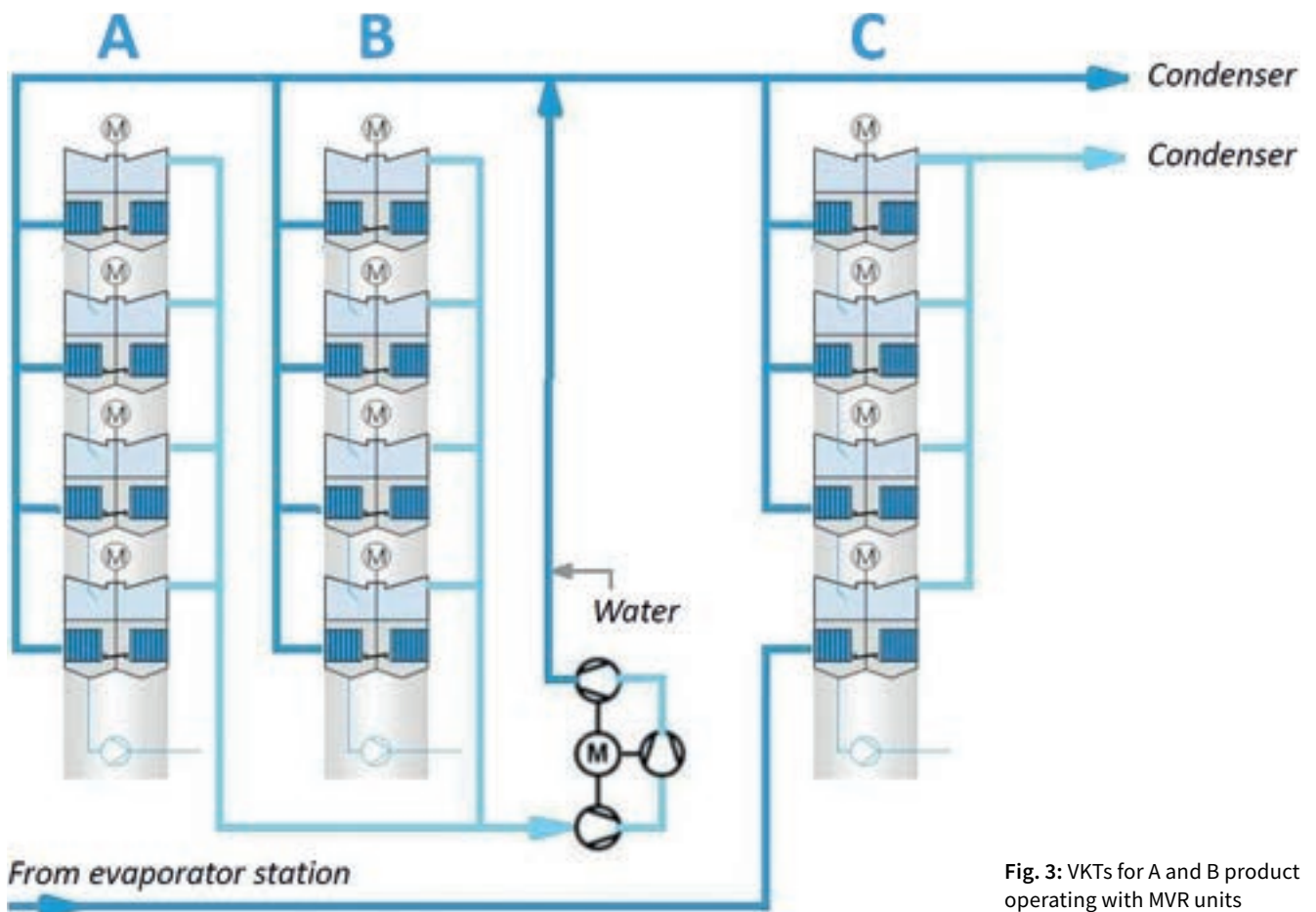


Fig. 3: VKTs for A and B product operating with MVR units

tion in the C VKT, the quantity of excess vapors resulting from the addition of water for steam cooling is not fully sufficient, which is why the last VKT chamber is directly supplied by the evaporator station. On the vapor side, the C VKT is equipped with its own condenser. This allows a vapor pressure to be set that is low enough for the typically higher temperature difference required for C product crystallization. The batch evaporating crystallizers for refined sugar and seed massecuite continue to be operated with steam from the evaporator station.

A combination of VKTs and mechanical vapor recompression as described in this energy study has been operated in a similar way since 1991 at the Aarberg sugar factory in Switzerland [9].

Table 2 shows the reduction in the energy demand – separated into the energy sources of steam and electrical energy – that can be achieved by applying mechanical vapor recompression. The steam demand is reduced by 60% compared to the base case, where all evaporating crystallizers are supplied with steam from the evaporator station. The electrical energy demand is increased by 28 kWh_{el}/t sugar, comprising of 26 kWh_{el}/t sugar for the vapor blower operation and additional 2 kWh_{el}/t sugar energy demand for operating the vacuum pumps at the separate condenser of the C VKT. For the sugar house, the total electrical energy demand sums up to 64 kWh_{el}/t sugar.

Table 2: Result of the energy study: Reduced energy demand for the sugar house

Energy demand	Base case	VKTs with MVR units
Steam to sugar house		
in kg/100 kg b.	10.2	4.3
in kWh _{th} /t sugar	437	185
Electrical energy / crystallizers		
in kWh _{el} /t sugar	36	38
Electrical energy / MVR units		
in kWh _{el} /t sugar	-	26

3.3 Design of VKTs and MVR units

For the design of the vapor compressor (MVR unit), pressure increase and volume flow are to be defined as precisely as possible for the normal operating point as well as for operational deviations such as chamber cleaning [10]. Therefore, both parameters are to be defined in close coordination with the technological VKT design. When selecting the VKT size, the aim is to settle on an optimal solution that takes into account both the heat exchanger surface installed in the VKT and the amount to be invested for the overall plant. Figure 4 shows an example of such a design output. In this overall view, two VKTs are combined with a mechanical vapor recompression station that consists of three vapor blowers installed in a row.

The VKT design for normal operation is based on the sugar house balance. During the cleaning phase, there is one chamber less available for crystallization, meaning that an increased pressure is needed in the remaining VKT chambers

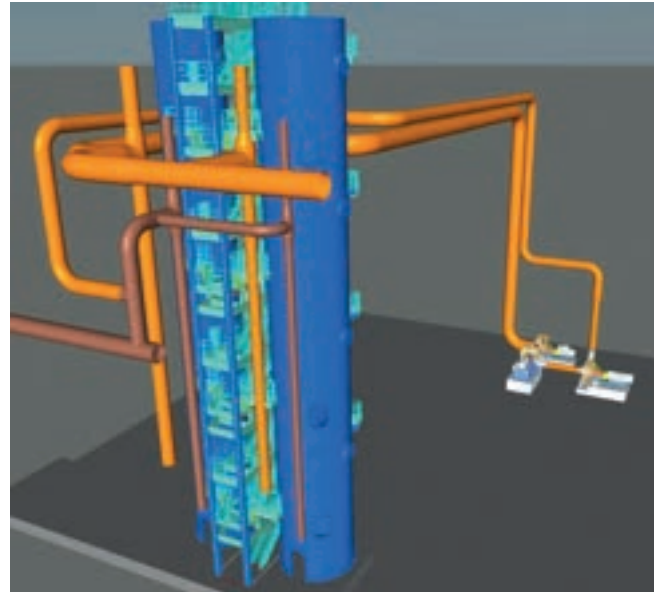


Fig. 4: Layout plan for two VKTs for A and B product with MVR units

at constant throughput and water evaporation. The necessary pressure difference for the VKT is calculated from the different operational states according to Table 3.

When determining the pressure loss of the overall system, special attention should be paid to the layout. The connecting pipelines that are selected should be as short as possible, taking the suction and discharge pipelines of the compressors into account. The sizes of the pipelines could be a limiting factor, since these are often larger than the nominal pipe size DN 1000, which in turn means higher investment costs and corresponding space requirements.

Figure 4 shows an example layout plan that also takes the local conditions into account. Here, two VKTs have been placed next to each other, while the three vapor blowers are located in an adjoining building (not shown). The pipelines for vapors and heating steam have a length of 40 m. The resulting pressure losses are summarised in Table 4.

Table 3: Design values for vapor and heating steam pressure in mbar abs. for A product and B product VKTs

Steam and vapor	A VKT	B VKT
Vacuum	220	220
Heating steam: normal operation	650	640
Heating steam: during boiling-out of one chamber	720	680

Table 4: Pressure losses in mbar in the vapor and heating steam system of the plant in Figure

Items	Suction side	Pressure side
Pipeline	0.59	2.87
90° elbow	0.96	4.02
T-pieces	1.94	4.46
Transition pieces	0.07	0.10
Entrainment separator	12.00	-
Control valve	3.00	15.00
Total	18.56	26.45

Table 5: Calculated design pressure values for the MVR station

Design group	Suction side	Pressure side
Piping pressure losses in mbar	18.6	26.5
VKT design pressure in mbar abs.	220	720
MVR design pressure in mbar abs.	201	747

The vapor and heating steam pressures (Table 3) required for the process and the pressure losses to be expected (Table 4) are used to obtain the design pressure values on the suction side and the pressure side for the MVR station in Table 5.

3.4 Further aspects for the operation of VKTs with MVR

Further attention should be paid to the vapor quality. Potential contaminations by entrained syrup droplets or even the “pull-over” of larger massecuite parts must be excluded. Especially in the case of the turbo compressors, entrained droplets or massecuite may damage the impeller when rotating at a high circumferential speed or result in uneven running of the impeller due to caking.

To significantly minimise the entrainment of syrup droplets, a separator has been integrated into the VKT. Two redundant level measurement sensors are installed, as well as an additional limit switch to reliably prevent the pull-over of massecuite. All three measurements are evaluated by the process control system, and emergency measures are initiated if specific alarm thresholds are exceeded.

4 Continuous crystallization and high dry substance content of the feed solution

A very high dry substance content in the feed solution with simultaneously high temperatures will lead to flash evaporation during addition of the feed solution, which carries the risk of fine crystal formation.

4.1 Addition of feed solution from below

In the present design of vertical continuous evaporating crystallizers (VKT), the feed solution for the VKT is added into the first chamber directly on top of the VKT and used in the ring pipe in the vapor chamber for wall cleaning (Fig. 5). From the second chamber onwards, the feed solution is added into the massecuite transfer pipe and, like in the first chamber, into the ring pipe in the vapor chamber for wall cleaning. This washes off incrustations, which are caused by the massecuite splashing upwards and which may shorten the working cycle (time between two boiling-out events) for the individual products [11].

The addition of feed solution is limited with regard to the dry substance content and the temperature. Adding a feed solution with an excessively high dry substance content (e.g.



Fig. 5: Ring pipe with feed solution for wall cleaning

more than 75%) and/or too high a temperature will lead to flash evaporation and thus to incrustations and the formation of fine crystals in the VKT. Such incrustations would shorten the working cycle of the VKT, which is undesired as it would then require more boiling-out processes. Moreover, spontaneously formed fine crystals would change the crystal distribution curve (e.g. a higher CV value).

This is solved by adding the feed solution below the liquid surface, in a similar manner to the batch process. As a result the feed solution is immediately mixed with the massecuite and cools down, thereby flash evaporation with the risk of fine crystal formation is avoided. One disadvantage is that the wall regions are no longer cleaned according to the current principle. It is therefore necessary to introduce a new “steam cleaning” working step into VKT operation.

BMA has already successfully implemented the described concepts in two A VKTs in Latin America. Just like the batch process, the feed solution is exclusively added in the bottom cone (Fig. 6). There is no other point of addition for feed solution. This concept was also applied in the cleaning phase for a chamber. As a result, it is no longer necessary to clean the walls in the vapor chambers using feed solution.

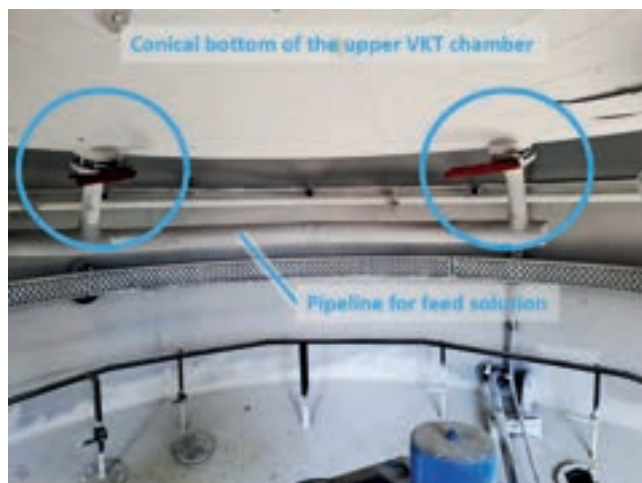


Fig. 6: Addition of feed solution from below into a chamber of the VKT

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4.2 Steam cleaning of the vapor chamber

Steam cleaning is carried out within 10 minutes during continuous operation. The steam is fed from the 1.5 bar distributor ("additional steam") for a short time into the vapor chamber. During this time, the automatic control system for the heating steam, vapors, fill level and dry substance content is temporarily frozen or shut down. As soon as a predefined pressure is reached in the vapor chamber, or after a defined period of time has elapsed, the addition of steam is stopped and the chamber is smoothly returned to continuous operation. Figure 7 shows an example of this cleaning action in a VKT chamber.

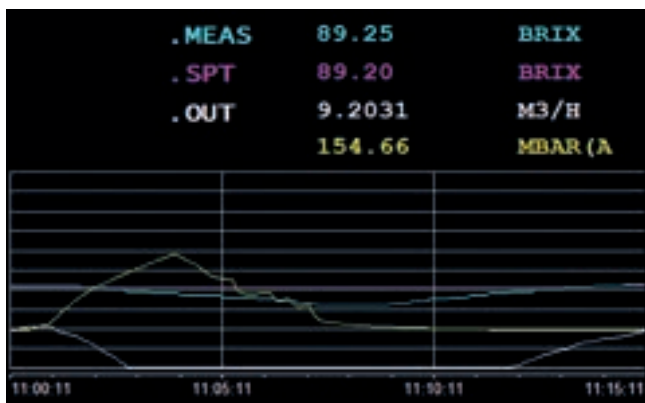


Fig. 7: Steam cleaning of a VKT chamber, as recorded by the process control system

A comprehensive test series for optimising the steam cleaning process was performed together with the customer, focussing on the following parameters during the steaming-out phase: steaming duration and final pressure achieved; influence on single control circuits; influence on other chambers; and the cleaning effect. The greatest challenge was how to control the feed solution during steam cleaning without influencing the other chambers: As it turned out, the least failures occur when the addition of feed solution is continued unchanged.

Figure 8a shows a chamber before cleaning, during operation and without wall rinsing. Initial signs of incrustation can be seen on the vapor chamber wall, the top cone, the agitator shaft, and on the massecuite transfer chute (on the left). After steam cleaning has been carried out, the walls and the internals above the massecuite level are free of incrustations (Fig. 8b).

It turned out that performing steam cleaning on a vapor chamber once per day is sufficient to prevent formation of larger incrustations and the working cycle from being reduced. The water quantity added for daily steam cleaning is negligible relative to the evaporation power of the VKT (smaller than 0.1%).

Even if regular steam cleaning is performed on the vapor chamber, it is still mandatory to regularly boil out the calandria.

5 Reduced energy input in the sugar house thanks to an increased dry substance content of the thick juice

To achieve the lowest possible temperature difference between the heating steam and the vapors, the general aim should be to add the feed solution to the VKT with the highest possible dry substance content that can be obtained in the sugar house, including its upstream plant sections. Thanks to the addition of the feed solution from below into the VKT, as described above, also those dry substance contents can be accepted that are clearly higher than what has been state of the art up to now. The increased thick juice dry substance content minimises the necessary water evaporation in the A VKT, thus reducing the amount of heating steam as well as the heating steam pressure required, with the installed heating surface remaining unchanged.

As illustrated by the example figures from Table 1, an increase of the dry substance content in the thick juice from 74% to 76% will lead to a vapor quantity in the A VKT that is reduced by 0.03 t/t sugar, and to a pressure difference for both VKTs (A and B product) that is reduced by 30 mbar. In

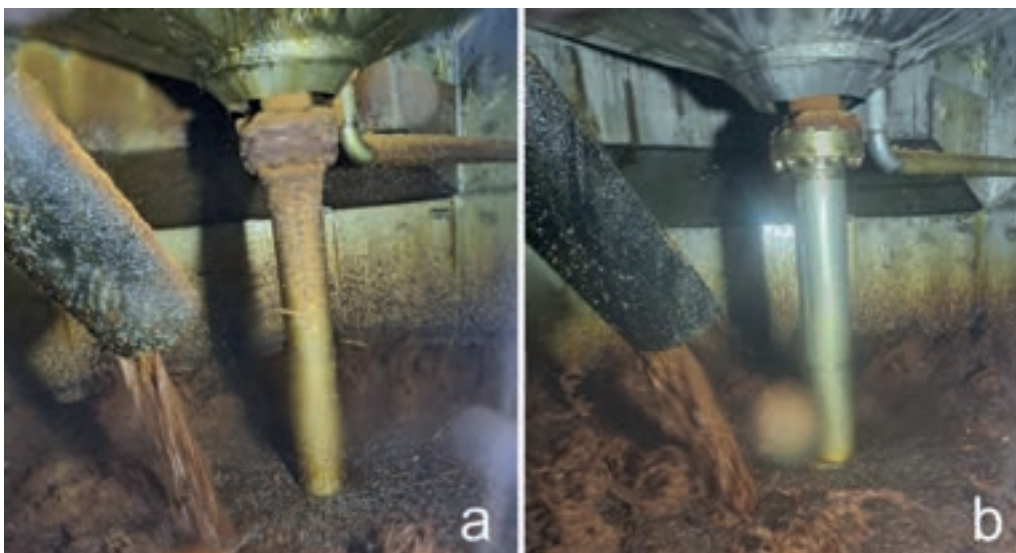


Fig. 8: Successful cleaning of a vapor chamber by steam cleaning: View of the vapor chamber before and after steam cleaning

Table 6: Minimised electrical energy demand in the sugar house

Energy demand	VKTs with MVR units Thick juice 74 % d.s.	VKTs with MVR units Thick juice 76 % d.s.	Improvement
Steam to sugar house in kg/100 kg b. in kWh _{th} /t sugar	4.3 185	4.2 179	-0.1 -6
Electrical energy / crystallizers in kWh _{el} /t sugar	38	38	-
Electrical energy / MVR units in kWh _{el} /t sugar	26	23	3

this way, the electrical energy demand for vapor recompression decreases by 3.0 kWh_{el}/t sugar (Table 6). With regard to the energy demand of the vapor compressors of 26 kWh_{el}/t sugar, this means a clear 12% reduction in the necessary energy demand for the vapor compressors.

Moreover, it should be noted that the steam demand from the evaporator station remains nearly unchanged for this calculated case of a sugar house with VKTs and mechanical vapor recompression, since the vapors from the evaporator station are only used for the batch evaporating crystallizers. Out of these batch crystallizers, only the A seed massecuite batch crystallizers will benefit from an increased dry substance content of the thick juice and feature a reduced heating steam demand.

6 Summary and outlook

Political framework conditions in response to climate change require to adapt the sugar manufacturing process: In essence, sugar production needs to become carbon-neutral within the foreseeable future, and the electrification of the sugar house will contribute to this. Concepts for this step have been published, and the associated technical plants are available and have been operated successfully for decades. The application of mechanical vapor recompression in the sugar house for the operation of evaporating crystallizers shows the way to transition from using thermal energy as the main energy source – in the form of steam from the evaporator station – towards electrical energy that ideally comes from renewable sources. In this scenario, it is essential to ensure resource-saving energy input by using systems that offer the highest efficiency.

Compared to batch-type evaporating crystallizers, crystallization in continuous evaporating crystallizers is characterized by a lower temperature difference required for water evaporation. Stirred systems in particular, such as the vertical continuous evaporating crystallizer (VKT), can also be operated at low temperature differences. This makes them ideal for operation in combination with mechanical vapor recompression units, the energy demand of which directly depends on the steam quantity to be compressed and the pressure ratio to be overcome.

The design of the “VKT with mechanical vapor recompression (MVR)” system must take into account all operating states, including start-up operation, full load and cleaning operation. Pressure losses in the pipelines for the vapors and

the heating steam must be minimised by a well-designed layout plan.

It has also been demonstrated that, for such a plant configuration with VKT and MVR, an increase of the thick juice dry substance content by 2% would lead to more than 10% reduction in the electrical energy demand for the vapor blowers. The

reduced water evaporation induces a reduced pressure difference at the VKT, which contributes to this leap in efficiency for the VKT-MVR system. The resulting annual savings in electrical energy for a sugar factory with 1000 t/d white sugar production with a 120-day campaign would amount to 372 MWh.

VKT operation with a high dry substance content in the feed solution requires a change in the way that the feed solution is added. By adding it from below to the massecuite in the VKT chamber, flash evaporation and potential fine crystal formation are avoided. Moreover, the cleaning process would then need to be changed from wall rinsing to regular steam cleaning of the vapor chamber.

Continuous evaporating crystallizers working without mechanical circulation always require a minimum level of water evaporation to ensure massecuite circulation. For this plant type, the concepts with a high dry substance content of the feed solution do not necessarily result in the lowest electrical energy demand. Only with stirred systems can these energy savings in crystallization be realised to the greatest possible extent.

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