Opportunities of cooling crystallization for white sugar production

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Abstract

Sugar cooling crystallization process was used for low sugar grade crystallization that carried out under certain conditions of higher supersaturation levels for further sugar crystallization after evaporating crystallization by decreasing sucrose solubility through temperature reduction. Recently there is a great interest with utilization of cooling and flash evaporation crystallization for white sugar production for energy cost saving in the sugar industry. This study is focusing on the utilization of an advanced sugar crystallization program to determine cooling crystallization parameters and conditions such as massecuite brix, crystal content and working temperature and pressure. A series of cooling crystallization experiments were conducted on a sugar crystallizer pilot at Al-khaleej sugar company "AKS" through 2017, 2018 seasons. Theoretical and practical simulation results are presented for sharing and discussions.

Keywords: Cooling crystallization; Sugar industry; Sugar production; Sugar processing

Introduction

1. Sugar crystallization theory and techniques:

Crystallization from aqueous sugar solutions relays on the saturation solubility has to be exceeded. Ways to achieve super saturation limits as follows:

Cooling : Decrease of sucrose solubility

Evaporation: Removal of water by evaporation, sucrose Con increases

Flash evaporation: Removal of water by expansion **(Austmeyer, Marwede 1987)**

The limitations of low temperature crystallization are low fluidity, hard handling and curing of the massecutie that related to the raise of viscosity. This viscosity limits allow only to get only the same crystal content achieved by high temperature boiling but at lower massecuite brix values. Accordingly low temperature crystallization's advantages indicated in steam and power reduction and high product quality correlated with low color formation and slow crystal growth rate indicated in getting better coefficient of variation "CV" of sugar crystals than obtained by ***Evapo-crystallization. Vavrinecz, G. (1978/79)..***

2. Cooling sugar crystallization theory and concept:

With decreasing the temperature the solubility of sucrose decreases and supersaturation of the solution is increased, accordingly sugar exhaustion is more in the lower temperatures. As shown in fig. I.1 at the same massecuite brix values crystal content values at 50°C are higher than that achieved at 75°C (at 88% brix CC% Masc. is 55.53% at 50°C while it is 44.59% at 75°C).

The material and energy balances have all suggested a very lucrative economical gain by using cooling crystallizers to replace two of four boiling (Clarke & Delgado, 2011). A lot of authors pointed out that 13 to 30% increase in magma's crystal content could be achieved by continuous feeding of 25% run off and cooling to ΔT 25 temperature degree difference**. *(Mantovani et el. 1988), (Reinfeld 1986), Buckholz, K.; Schliephake, D. (1989), Schliphake et al 1987), Lyle 1950***

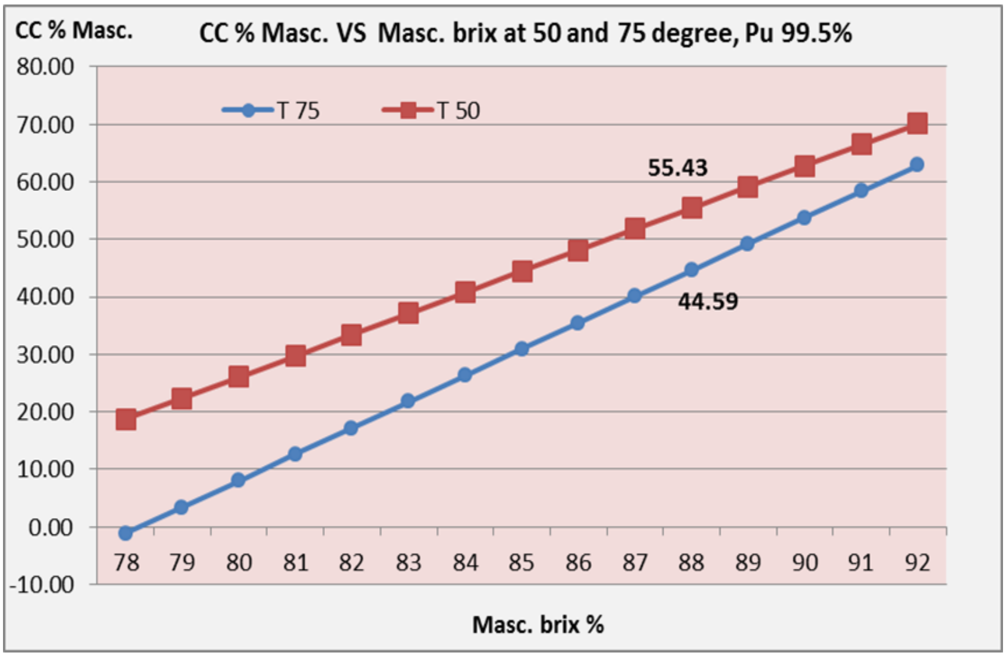

Fig. I.1. Temperature effect on sucrose exhaustion of R1 massecuite at 50, 75°C.

Figures I.2,and 3 illustrate the energy balance of R1 massecuite boiling under high and low working temperatures. At lower working temperature 51°C the amount of steam needed to get massecuite crystal content 57% is 3.91Ton/hr obtained at 89% massecuite brix. While at higher working temperature 73°C the steam amount needed to get the same CC value is 5.62 Ton/hr obtained at 91% massecuite brix and the same 20 ΔT(steam →Masc). This indicates 30% reduction in steam consumption of sugar boiling at low working temperatures and pressure which give less color formation.

Sugar boiling: R1 cane sugar Refinning — ergy balance and massecuite crystal content calculations of vacuum pans at working conditic

Inputes:

MLss	1.10	%
Sugar purity	99.98	%
Masc. purity	99.50	%
Wiklund's coefficients		
a	0.10	
b	0.71	
c	0.36	

Energy balance:

HTC	373.53	w/m2k	TΔ (Steam→Masc)	20.00	°C
HSA	475.00	m2	Steam temperature	93.10	°C
Heat amt.	3548.56	kw	Steam Pressure	0.79	bar a
Heat amt.	12774827	KW/hr.	Vapor pressure	0.25	bar a
Steam Wt.	5.62	T/hr.	Latent heat Steam	2271.99	Kj/kg
Vapor Wt.	5.45	T/hr.	Latent heat Vapor	2344.89	Kj/kg

TΔ (steam→vapor)	27.86	°C
ML NS/W	0.05	%
ML percentage	42.91	%
Melassigenic factor	1.00	%
MLss "calculated"	1.10	%

Legend:

Masc	Massecuite
ML	Mother liquor
DS	Dry substances
BPE	Boiling point elevation
SS	Supersaturation
NS/W	Non sugar water ratio

Masc. Temp. °C	Masc. brix %	Sugar %	Water %	S/W ratio g/100 g	Solubility (S/W)sat g/100 g	Sugar to be crystallized g/100 g	Crystal content % Masc. DS	Crystal content % Masc.	ML brix %	ML purity %	BPE °C	Vapor Temp. °C	Vacuum pressure mbar a	ML viscosity cp	Masc. viscosity cp
73.10	91.00	90.55	9.00	1006.06	337.93	634.33	62.74	57.09	79.03	98.69	7.86	65.24	250.34	131.56	30917.42

Fig. I.2 Crystal content and energy balance at 73 ° C of R1 massecuite.

Sugar boiling: R1 cane sugar Refinning — ergy balance and massecuite crystal content calculations of vacuum pans at working conditic

Inputes:

MLss	1.10	%
Sugar purity	99.98	%
Masc. purity	99.50	%
Wiklund's coefficients		
a	0.10	
b	0.71	
c	0.36	

Energy balance:

HTC	266.31	w/m2k	TΔ (Steam→Masc)	20.00	°C
HSA	475.00	m2	Steam temperature	71.00	°C
Heat amt.	2529.96	kw	Steam Pressure	0.32	bar a
Heat amt.	9107838	KW/hr.	Vapor pressure	0.10	bar a
Steam Wt.	3.91	T/hr.	Latent heat Steam	2330.32	Kj/kg
Vapor Wt.	3.81	T/hr.	Latent heat Vapor	2391.34	Kj/kg

TΔ (steam→vapor)	24.68	°C
ML NS/W	0.04	%
ML percentage	42.87	%
Melassigenic factor	1.00	%
MLss "calculated"	1.10	%

Legend:

Masc	Massecuite
ML	Mother liquor
DS	Dry substances
BPE	Boiling point elevation
SS	Supersaturation
NS/W	Non sugar water ratio

Masc. Temp. °C	Masc. brix %	Sugar %	Water %	S/W ratio g/100 g	Solubility (S/W)sat g/100 g	Sugar to be crystallized g/100 g	Crystal content % Masc. DS	Crystal content % Masc.	ML brix %	ML purity %	BPE °C	Vapor Temp. °C	Vacuum pressure mbar a	ML viscosity cp	Masc. viscosity cp
51.00	89.05	88.60	10.95	809.18	261.33	521.71	64.15	57.13	74.46	98.64	4.68	46.32	100.39	158.14	37162.35

Fig. I.3 Crystal content and energy balance at 51 ° C of R1 massecuite.

ll. Experimental:

A sugar crystallization pilot unit constructed at AlKhaleej Sugar Co. AKS for vacuum cooling crystallization of different sugar grades in period 2017, 1081 to study the effect of cooling on the productivity and quality. Trials were performed for R2 run off in both batch and continuous process under vacuum 50 mbar a where the purpose is to convert the batch boiling of R3 sugar product into a continuous type.

Sugar crystallizer pilot units as scheme shown in Fig. II.1 is:

- Two BMA cooling crystallizers 10 m^3 capacity working under 150 mbar a
- One horizontal SEDEL sugar beater 15 m^3 capacity working under 50 mbar a
- Two SEDL booster vacuum pumps of 5T/h capacity working in series
- BMA Massecuite pump 12 m^3/hr capacity, brix 86: 92%
- Existing process R3 strike receiver 75 ton capacity, its massecuite pump.

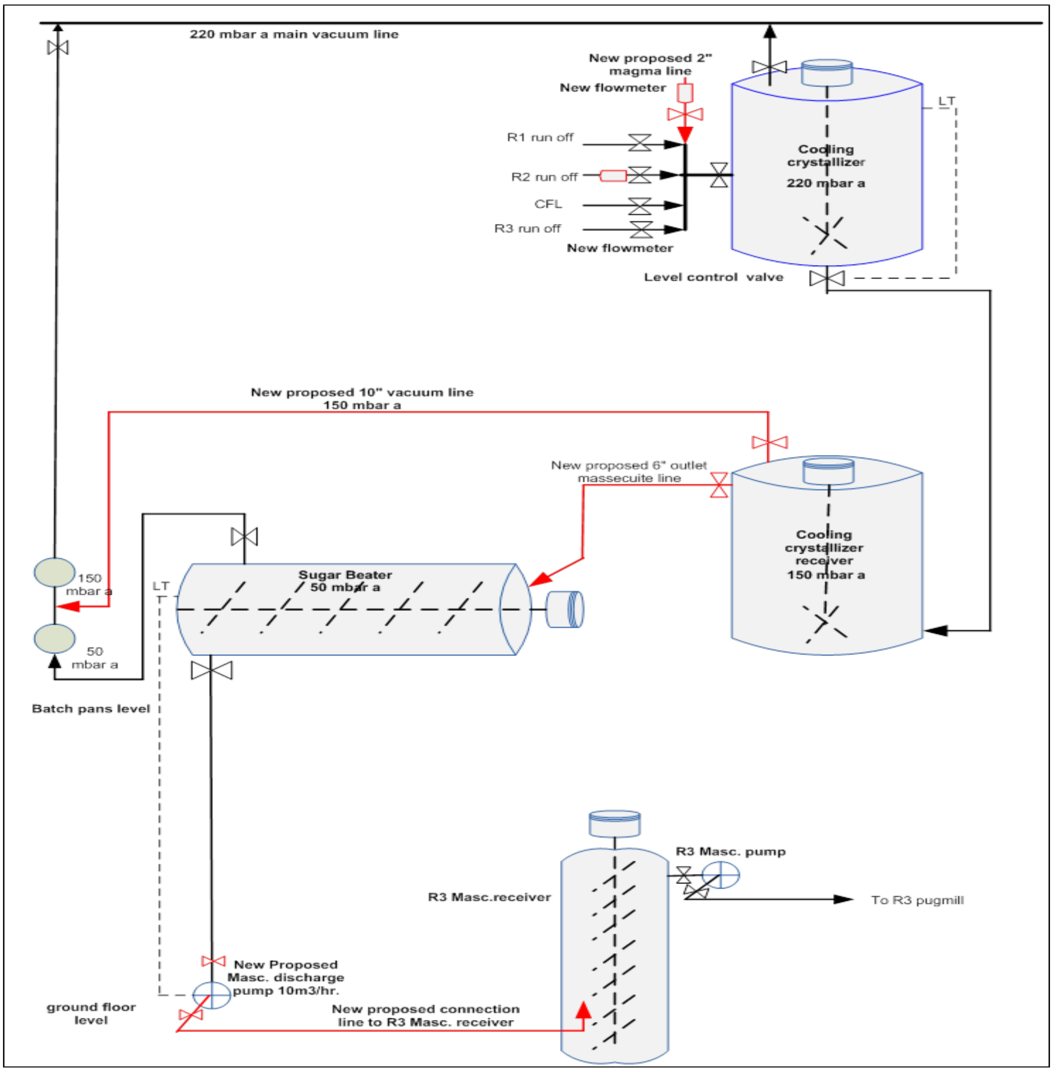

Fig.II.1. Scheme of R3 massecuite production vacuum cooling sugar crystallizer pilot

Trial procedure:

a) Batch process at sugar beater of three vacuum stages:

- Hot R3 or R4 run off 90°C is fed till mid shaft level then concentrated to 82% brix under vacuum of 250 mbar a using top booster vacuum pump and using steam jacket of 1.2 bar a for evaporation
- 20 ml of slurry is added, steam jacket closed then Masc. kept 45 minutes at 75°C, and masscuite brix gradually increases to 84%.
- 2^{nd} booster vacuum pump running and massecuite kept under 150 mbar & 60°C
- Vacuum is increased to 50 mbar a by increase pumps speed and massecuite gradually cooled to 45°C within 45 minutes till get massecuite brix around 86%.

b) Continuous vacuum cooling CVC at cooling crystallizers and sugar beater:

R3 continuous vacuum cooling crystallization were performed as per scheme shown in Figures II.1 and 2 and the following steps:

- m3/hr of seed magma of 89% brix and 6 m^3/hr R2 run off 80% brix are continuously fed into 1st cooling crystallizer from bottom through a manifold feed header and vacuum is maintained at 220 mbar a using process vacuum network
- AT 90% massecuite level the bottom control valve open and fed 2^{nd} cooling crystallizer from the bottom and vacuum maintained at 150 mbar a by runing1st booster vacuum pump while temperature gradually cooled to 60° C.
- The massecuite leaving 2^{nd} cooling crystallizer from over flow line into sugar beater from bottom’s front side at brix 85% which maintained

under mid shaft level by massecuite pump, and keep vacuum under 50 mbar a using two booster vacuum pumps in series

- The massecuite of 45°C and approximately 88% brix is withdrawn from bottom's back side by the massecuite pump located in the ground level and pumped into R3 strike receiver then R3 centerfugals
- The trial was kept running in a continuous operation for three days and a scheduled samples taken into lab for analysis
- Sugar separated from run off using lab centrifugal and crystal content calculated form both purity of sugar and run off.

Different attempts were performed on high grade boiling for pure and vacuum cooling crystallization and all presented a better product productivity and quality in comparison with evaporating crystallization. ***Vaccari, G. and Mantovani, G. (1996), Hakan Gros, Teuvo Kilpio, Juha Nurmi (2001), Krupp Gmbh, DE 3810181 C1, (1988).***

Note: R1 referring to refined sugar grade1 resulted from 1st sugar crystallization (boiling) of concentrated sugar liquor and R1 referring to sugar grade 2 resulted from 2nd sugar crystallization (boiling) of run off 1 from 1st sugar crystallization and so on.

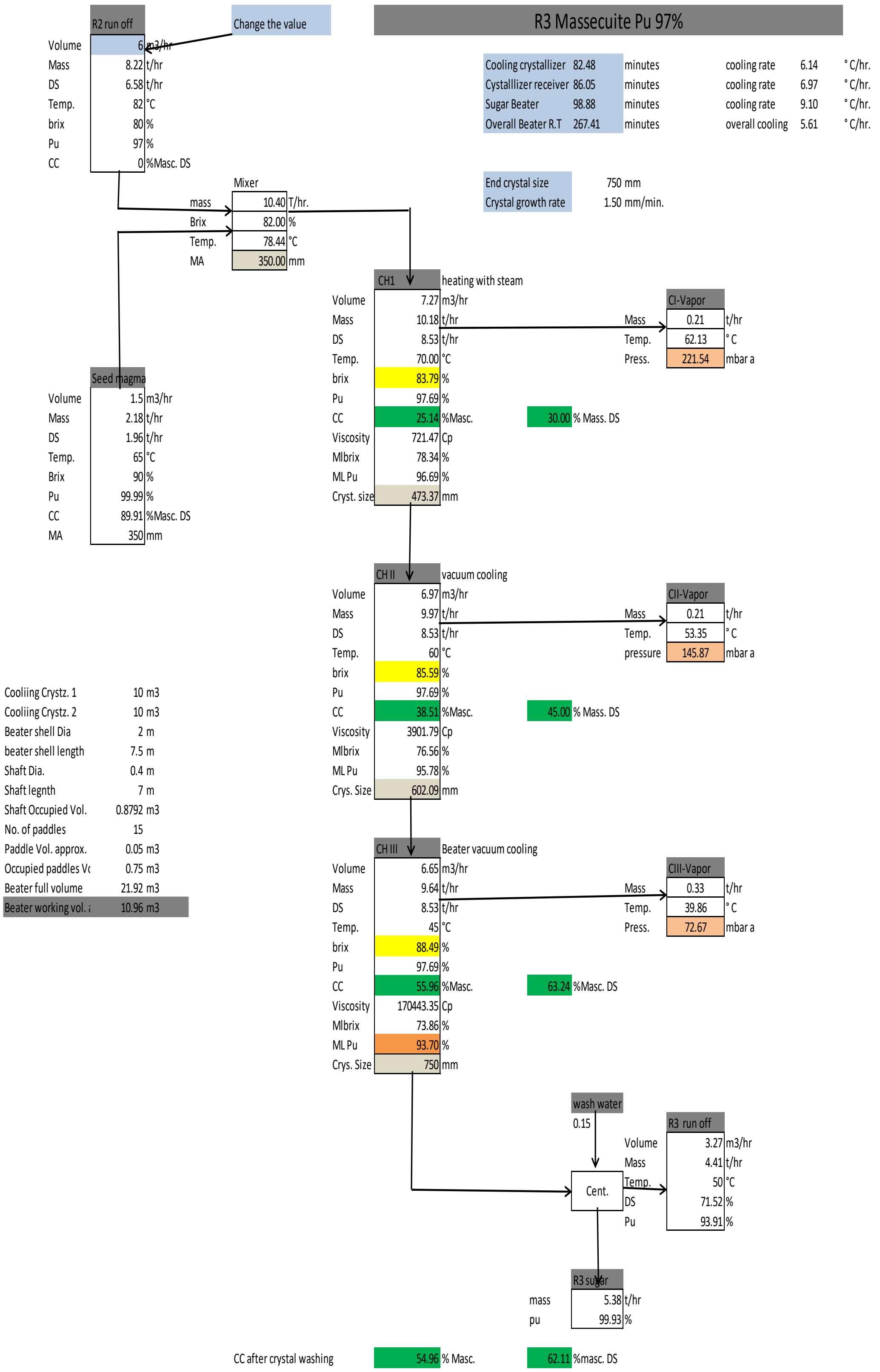

Fig. II.2. Mass and heat balance of R3 continuous vacuum cooling crystallization

III. Results and Discussions:

Table III.1. Lab result of R3 batch cooling crystallization on sugar beater 4/4/2016

1. Trial's operating conditions	1ST stage 250 mbar a	2ND stage 150 mbar a	3rd stage 50 mbar a
Start time	10.20 am (seed)	11.05am	11.50 am
End time	11.05 am	11.50 am	12.40 pm
Time in hour	0.75	0.75	0.83
Total time in hour	2.33		
Actual Temp. °C	68	58	46
Actual vacuum mbar a	230	165	65
Sugar beater current in amp	15.8	15.5	15.8
2. Trial's lab results	1ST stage 250 mbar a	2ND stage 150 mbar a	3rd stage 50 mbar a
Massecuit brix %	81.6	83.2	85.4
Massecuite purity %	97.06	97.07	97.12
Massecuite viscosity in cp	667	784	5450
Massecuite color in IU	3199	3268	3373
MA in micron	43 (Grain)	349	424
CV %	19	32	39

Table III.2. Lab results of R4 batch cooling crystallization on sugar beater 3/4/2016

Trial's operating conditions	1ST stage 250 mbar a	2ND stage 150 mbar a	3rd stage 50 mbar a
Start time	4.15 pm	4.35	5.50 pm
End time	4.35	5.50	6.35
Time in hour	0.33	1.15	0.75
Total time in hour	2.3		
Actual Temp. °C	70	60	40
Actual vacuum mbar a	235	165	70
Beater current in amp	15	15	15.5
Trial's lab results	1ST stage 250 mbar a	2ND stage 150 mbar a	3rd stage 50 mbar a
Massecuit brix %	81.6	83.4	87.8
Massecuite color in IU	6200	6249	6058
Massecuite purity %	94.93	94.7	94.76
MA in micrin	31 (Grain)	425	675
CV %	19	25	31

Results of batch cooling crystallization for R3 boiling that shown in table III.1 indicate achievement low productivity and quality indicated in low crystal growth 2.7 micron/min within 140 minutes at 46°C, low MA 424 micron and high coefficient of variation CV 39%. Also Low Massecuite brix value 85.4% at 46°C indicate getting low crystal content 42% as shown in Fig. I.1.

Batch cooling crystallization results of R4 shown in Table III.2 indicate that achieving high productivity and quality in the terms of high MA 675 micron and crystal growth rate 4.8 micron/min at 40°C and low coefficient of variation CV 31%. Low massecuite brix value 87.8% at 40°C indicates high crystal content 52%.

Color level slightly increased by the concentration and still low compared to the actual operating working color values that is performed at higher temperatures. Viscosity values of massecuites still in the operating working limits.

Practically batch cooling crystallization could be applied with certain limits of vacuum pressure and temperature as concluded from bad results of R3 batch cooling crystallization and also design criteria of vacuum pan. So the working operating conditions for batch cooling crystallization could be in the range of vacuum 175 mbar a and temperature 65°C.

Table III.3. Lab results R3-CVC, March 2017 under 50 mbar a, Masc. Temp. 42° C

Parameter	Seed magma 25% run off mass	R2 Run off from evaporator	R3 Massecuite from sugar beater	Lab centrifuge	
				Run off	Sugar
°Brix	90.3	80.00	88.20	73.80	
Polarization °Z	89.76	77.48	86.40	69.80	
Apparent Purity %	99.4	96.85	97.96	94.58	
pH		6.50			
Color, IU	443	3629	2279	5582	330
Viscosity, Cp		894	44676	487	
Crystal Content %	49.7		54.99		
M.A., mm					0.72
% C.V.,					26

Table III.4. Lab results R3-CVC, Sep. 2018 under 50 mbar a, Masc. Temp. 38° C

Parameter	Seed Magma 25 % R2 run off mass	R2 Run off from evaporator	R3 Massecuite from Sugar beater	Lab Centrifugal	
				Run off	Sugar
° Brix %	90.80	82.20	88.48	72.00	
Polarization	90.24	79.96	86.78	68.55	98.02
Apparent Purity %	99.38	97.27	98.39	95.21	
PH		6.9	6.8	6.40	
Color, IU	468	3008	1020	2622	208
Crystal Content %	49		57.14		
M.A., mm	0.48				0.61
C.V., %	26				33

The results of R3-continuous vacuum cooling “R3-CVC” of the two separate trials that is shown in tables III.3,4 confirmed on the possibility of achievement the same crystal content values up to 60% with better quality indicated in high MA 0.72 -061 mm, low coefficient of variation CV 26-33 % and low massecuite color 1020 IU. This crystal content 54.99 -57.14 achieved at lower brix values 88.2, 88.5% compared to 91% brix of evaporating continuous crystallizer and at nearly the same residence time 3 hours.

Less color formation of R3 massecuite indicated in the low color values 2279, 1020 IU of R3 massecuite compared to the actual working values of R3 boiling 3500 IU at higher temperatures. High color values of the produced R3 sugar due to using less wash water quantity for crystal washing. Also massecuite viscosity value 44676 cp are slightly higher than the operating working limits of 36000 cp.

The overall operation cost could be reduced below 50% including the reduction of sugar drying and conditioning that related to low sugar temperature by CVC process optimization in the two axis: vacuum energy cost reduction and utilization of low pressure steam in the first chambers of the crystallization tower.

In CVC technique there is no utilization of heating steam and the only driving force is the vacuum or cooling rate, so with controlling temperature reduction by vacuum, usage of very little heating steam quantity and maintaining brix of run off and seed magma at highest possible values the rate of crystallization could be maintained at 6 g/m^2.minute as the actual working crystallizers.

Summary

This Study summarize attempts to use cooling and flash evaporation crystallization in white sugar production for higher productivity with energy cost saving. A series of tests performed at sugar crystallizer pilot at Al khaleej sugar Co. AKS using data of sugar crystallization program that detect and optimize process parameters & conditions.

Vacuum cooling process is a new trend in sugar industry for cost reduction and quality improve and already applied in a small scale in some cane sugar refineries and beet sugar factories in Europe and South Africa that achieve optimum sugar production. The trials are conducted on R3 and R4 continuous boiling; the obtained results showing achieving higher productivity and quality with minimum cost especially for continuous cooling crystallization CVC that strongly will encourage the sugar producer to start investment and implementation.

Practically batch cooling crystallization could be applied in white or refined sugar and recovery boiling with some limitations in the range of vacuum pressure 175 mbar a and 65°C. While continuous vacuum cooling crystallization could be widely applied economically in white or refined sugar boiling under vacuum pressure 100 mbar a with using very little quantity of low pressure heating steam 500- 800 mbar a that enhance sugar crystal growth and accelerate the process rate.

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الملخص العربي

فرص عملية البلورة بالتبريد لإنتاج السكر الابيض

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تشير هذه الدراسة الي عملية البلورة بالتبريد المستخدمة في استخلاص السكر من الطبخات ذات الجودة المنخفضة والتي تجري عند ظروف معينه من تركيزات عليا لفوق التشبع للسكروز وذلك بخفض زوبانية السكروز خلال عملية التبريد.

حديثا هناك اهتمام كبير ومحاولات لاستخدام البلورة بالتبريد بنظام التبريد الممتد وايضا التبريد مع الغليان اللحظي والذي يجري باستخدام ضغط تفريغ في انتاج السكر الابيض بهدف توفير الطاقة بصناعة السكر.

هذه الدراسة تركزعلي استخدام برنامج حديث لبلورة السكروز في تعيين كافة الظروف والبارميترات المطلوبة لاجراء هذه العملية مثل درجة بركس الماسكويت و درجة حرارة التشغيل والكسب البلوري والضغط المطلوب.

سلسلة من التجارب تم اجراءها علي وحدة تجارب صناعية بشركة الخليج للسكر خلال مواسم تكرير السكر عامي 2017 و 2018

الدراسات النظرية ونتائج المحاكاة العملية التي تمت تحت درجات حراره منخفضه وضغوط تفريغ عالية بينت زيادة الإنتاجية مع تحسن جودة السكر تم عرضها هنا للمشاركة والنقاشات.