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Massecuite conditioning, how to improve low raw massecuite curing.

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Abstract

Low-grade massecuite centrifugation operation is a critical step in the process of sugar production. Indeed many factors affect the performance of the continuous centrifugals. Among them physical characteristics of the product to be treated (such as non-sugar content, temperature, viscosity, crystal content, size of the sugar crystal) are of the foremost importance. On the other hand, the sugar industry permanently challenges ways to reach higher throughput, lower losses and reduced costs. To answer both of those general requirements, a range of equipment is on the market with the aim of conditioning the massecuite before centrifugation. A review and a comparison of the equipment (massecuite dilution and reheater) are undertaken from a theoretical and practical point of view.

Introduction

The purpose of the crystallisation process being carried out in vacuum pans and crystallisers, is to maximise sugar exhaustion from the massecuite mother liquor. In low-grade massecuites in particular. resultant high brix, high viscosity massecuite creates difficulty to efficiently and economical separate the sugar crystals from the mother liquor during centrifuging. It is therefore normal to provide some form of "massecuite conditioning" immediately prior to centrifuging to improve the separation process.
Ideally conditioning should be done without or minimal re-dissolution of already crystallised sugar. At the same time aid the separation to acquire a desired sugar quality and maximise centrifugal capacity.

There are two basic approaches used for massecuite conditioning namely dilution and heating. This evaluation is to compare the merits of the different systems.

Numerous authors have discussed the different methods of massecuite conditioning, so we will not go into great detail on the individual systems.
Dilution by the addition of water direct to massecuites is no longer practised due to the negative effects it has on the molasses purity, as reported by McGinnis (S Jour 37, 1974/75).
Dilution system using are available today that mix molasses and massecuite, similar to technique of BMA and Fives Cail.
Heating system like the Stevens Coil (A.H.Stuhlreyer Beet Sugar Jour 2nd Edit), Crystalliser heating (E.Hugot series 7), direct heating (Reinhold Hemplelmann 2002 ISSCT workshop) and finned tube re-heaters (Kirby et al)

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Basis for Evaluation

For purpose of this evaluation we have considered a case for a factory slicing 6,000 tons of beets per day and producing 20 tonnes per hour of low grade massecuite. Also used as an example what we regard as a reasonably typical beet low grade massecuite having a refractometer brix of 94 degrees and an apparent purity of 76. For determination of mother liquor supersaturation the formulae from Z. Budnik et al Sugar Tech Manual has been used and it has been assumed that the molasses has the following coefficient a=0.230; b=0.770; c=1.500.

It is also assumed that the total massecuite and mother liquor obeys the viscosity relationship detailed in the formulae of Z. Budnik et al Sugar Tech Manual. An illustration of this relationship and of the effect that temperature has on massecuite and mother liquor viscosity during the crystalliser cooling stage is shown in Figure 1. It can be seen that there is a steep viscosity increase when the cooling massecuite drops below 50°C

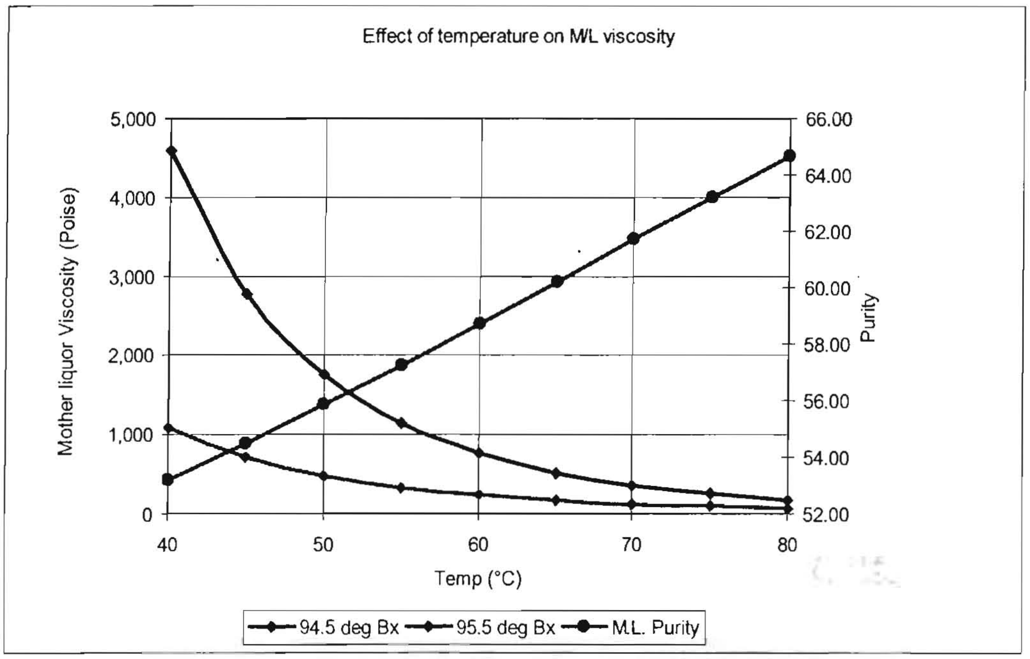


Figure 1 - Effect of Crystalliser cooling on massecuite viscosity

Examples of modern conditioners:

Although Stevens coil re-heaters are still common in a lot of existing factories, they are not generally the choice for new installations. When new more modern installations are considered there are alternatives choices:-

Alternative Methods for C-massecuite Conditioning

1) Re heating in the last section of a vertical crystalliser.
2) Re heating in a dedicated finned tube re heater.
3) Diluting with an inline dilutor/conditioner.
4) Re heating by direct steam injection of steam into the massecuite.

Alternative evaluations

1) *Re-heating in a crystalliser.*

Consider a low grade crystalliser is divided up into two sections one for cooling and the other section for heating. The cooling section is sized for a thirty-six hour cooling time 0.81 deg C per hour. (480 cu M).
The heating volume is sized adequately to heat the massecuite to saturation point while maintaining the same heating surface to volume ratio of 1.3 as per the cooling section. Giving it a 12-hour retention, (160 cu M).

For the purpose of the evaluation the cooling volume has been divided into two sections, both cooling and heating waters are counter current to massecuite flows.
Using a model with the parameters shown in Figure 3 the mother liquor film is reduced to a level of saturation acceptable for easy centrifugal separation.

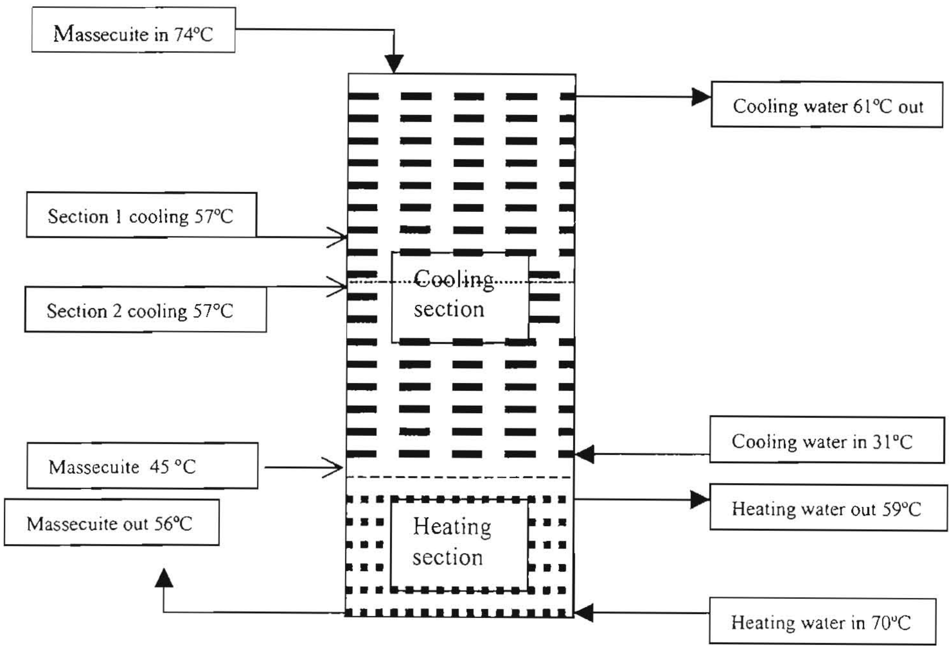


Figure 2 - Model of crystalliser cooling and heating scenario.

			Inlet area 1	Oulet area 1	Inlet area 2	Oulet area 2	Inlet area 3	Oulet area 3
Massecuite	Flow	t/h	20.0	20.0	20.0	20.0	20.0	20.0
	Brix	%	94	94	94	94	94	94
	Purity	%	76	76.0	76.0	76.0	76.0	76.0
	Crystal content	%	30.0	36.0	36.0	39.5	39.5	41.0
	Nutch brix	%	91.4	90.6	90.6	90.1	90.1	89.8
	Nutch purity	%	64.8	61.1	61.1	58.6	58.6	57.4
	Temperature	°C	74.0	57.0	57.0	45.0	45.0	56.0
	Supersaturation		1.24	1.29	1.29	1.32	1.32	1.12
	Film Surpersaturation		1.45	1.48	1.48	1.49	1.14	0.95
	Enthalpy	kJ/kg	127	94	94	73	73	91
Water	Flow	t/h	9.25	9.25	8.69	8.69	8.16	8.16
	Temperature	°C	61.0	44.0	44.1	32.1	59.3	70.3
	Enthalpy	kJ/kg	255	184	184	134	248	294
	DT MC-water	°C	13.0	13.0	12.9	12.9	14.3	14.3
	Volume	m3	240		240		160	
	S/V	m-1	1.30		1.30		1.30	
	Surface	m2	312		312		208	
	DT log	°C	13.0		12.9		14.3	
	Heat coef.	w/m2.°C	45.0		30.0		35.0	
Residence time			18.0		18.0		12.0	

Figure 3 - Balance of cooling and heating of a low raw massecuite with classical vertical cooling crystalliser

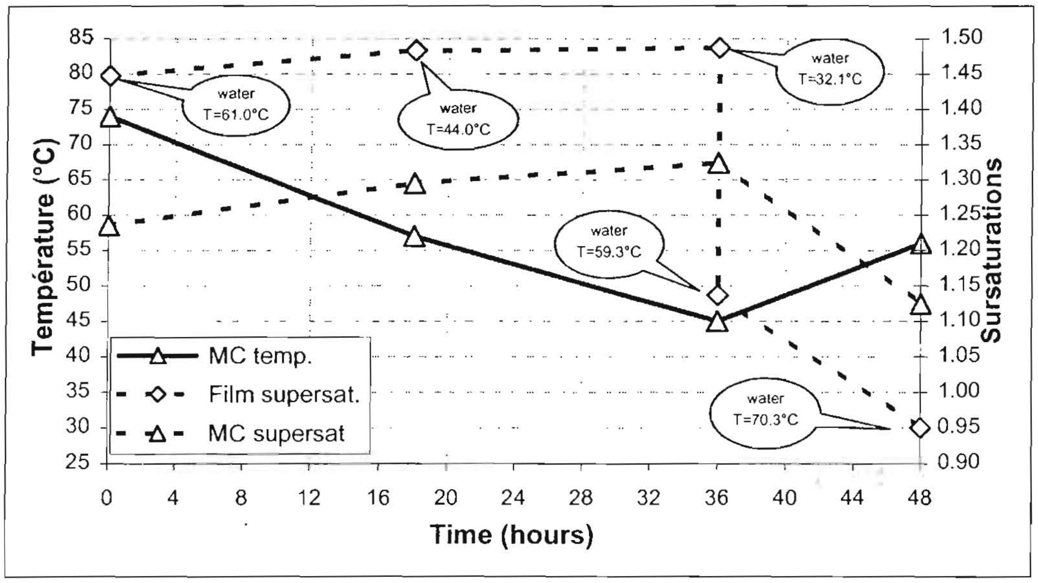


Figure 4 - Corresponding crystalliser heating profile

Temperature profiles are presented graphically in figure 4, it comprises of the average massecuite supersaturation and the expected supersaturation of the massecuite in close proximity of the heating/ cooling elements

The average saturation of the massecuite close to the heating element is near to saturation. Therefore the crystalliser method of heating needs very good control and management, to reduce the risk of localised heating.

A disadvantage of this type of installation is the size and cost of the equipment required.
The thermal balance is optimised in order to maintain the difference of temperature between the water and the massecuite so it is kept as constant as possible during the phase of cooling and heating. As can be noticed from figures 3 and 4, during the cooling phase, the supersaturation of the massecuite in close contact with the cooling tubes is higher than 1.45. This leads to a potential risk of fine crystal sugar formation or local encrustation on the cooling tube surface. On an other hand, during the heating phase, the temperature of the water in the tubes is such that the massecuite could be locally under saturated, in particular just before leaving the crystalliser.
In conclusion it appears from this review that large vertical crystalliser with classical surface/volume ratio ($S/V<1.3\ m^{-1}$) are, on one side, advantageous because they allows a smooth evolution of the massecuite characteristics thank to a long residence time. But on an other side, they are disadvantageous because in reason of the low relative surface available the risk of fine formation in the cooling section and sugar dissolution in the heating section are high.

2) *Re-heating in a finned heater exchanger.*

To counter the high volumes of the vertical crystallisers, finned tube heater exchanger were developed in order to reduce the temperature differences between the water used for heating and that of heated massecuite. Which is normally less than 10 degrees with type of system.

The comparison of Finned tube heating has been sized on the same criterion as that of the crystalliser heating system, Ref to Figure 7.

Finned tube re-heaters as in the Green Smith type have a heating surface to volume ratio that is very high, generally 100 or greater that enables the use of low heating water temperatures and being small, in size, reduces the massecuite retention time in direct contact with the heating section.
The positioning of a re-heater is normally close to the cooling crystalliser. This assists in reducing friction losses and head requirements as would a cold massecuite. Normally with this type of installation pumping of cold massecuite is not necessary.

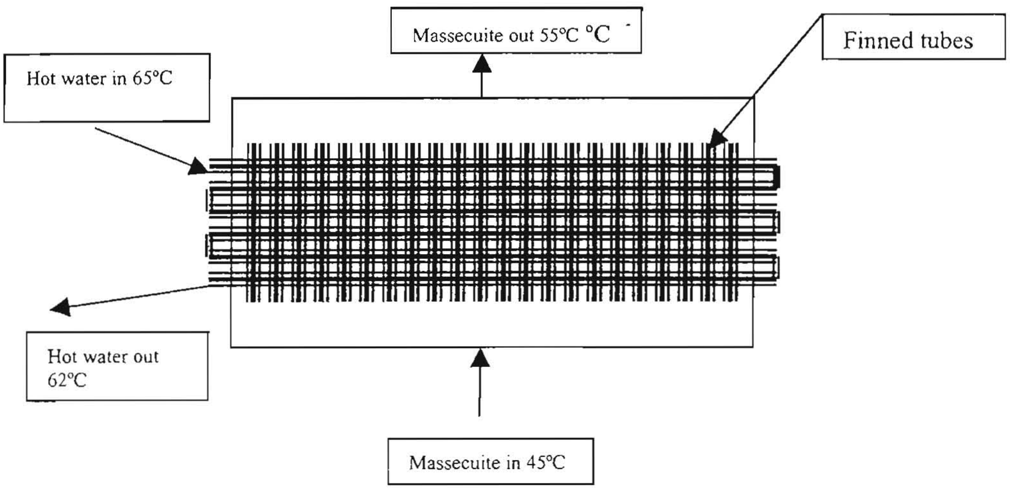


Figure 5 - G.A of a finned tube re-heater

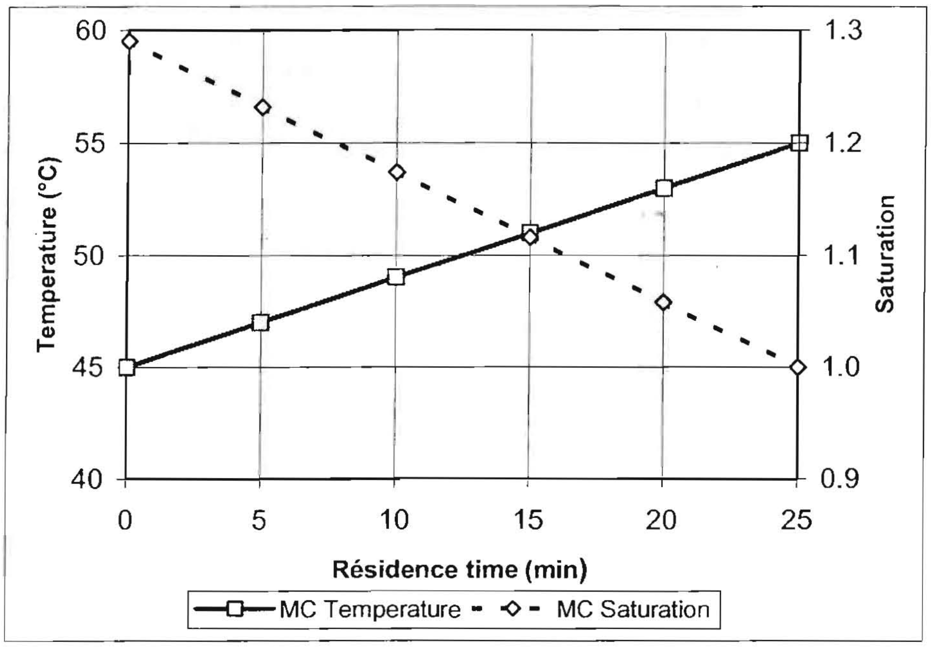
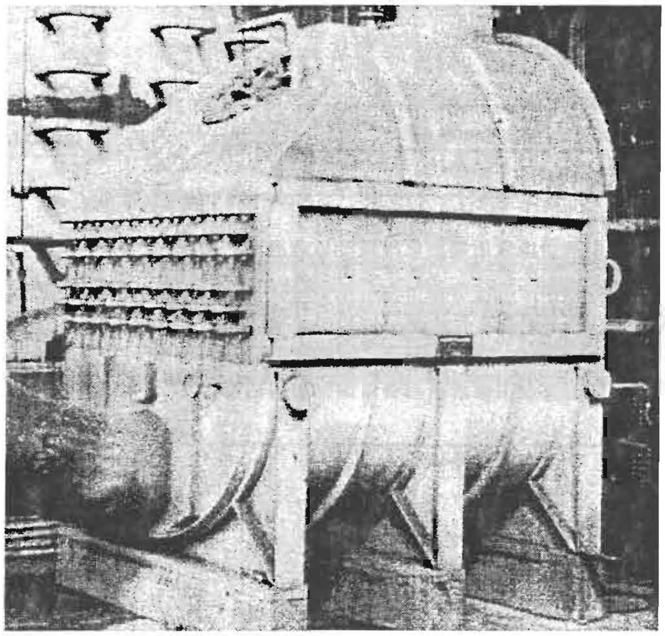


Figure 6 - Re-heater temperature & saturation profile

Figure 6 assumes that the flow of massecuite through a conventional finned heater is linear, as it has a high heating surface with narrow massecuite voids. It is considered that a correctly designed heater does not channel as it is self regulating, with high massecuite flow passing over the heating elements less heat is absorbed. This tending to slow the rate of throughput, due to its change in its saturation/viscosity. When the rate slows additional heat is taken in, again altering the massecuite allowing the flow to increase.



A Typical massecuite reheater

			Inlet	Oulet
Massecuite	Flow	t/h	20.0	20.0
	Brix	%	94	94
	Purity	%	76.0	76.0
	Crystal content	%	41.0	41.0
	Nutch brix	%	89.8	89.8
	Nutch purity	%	57.4	57.4
	Temperature	°C	45.0	55.0
	Supersaturation		1.26	1.14
	Film Surpersaturation		1.14	1.02
	Enthalpy	kJ/kg	72	90
Water	Flow	t/h	23	23
	Temperature	°C	54.6	64.6
	Enthalpy	kJ/kg	229	271
Thermal Exchange	DT MC-water	°C	9.6	9.6
	DT of DT			0.0
	Volume	m^3	3.5	
	S/V	m^{-1}	114	
	Surface	m^2	400	
	DT log	°C	13.19	
	HTC	$w/m^2.°C$	20.0	
Residence time		hrs	0.3	

Figure 7 - Balance of finned tube reheater.

Advantages of a finned re-heater are that it has a large heating surface area in a very compact area. For this particular model of 400sq m heating surface it has a massecuite volume of 3.5 cu M. Giving a heating surface to volume ratio of 114 m2/m3, with a massecuite average retention time of 20 minutes within the heating section, therefore eliminating the risk of crystals dissolution.
Another advantage is that they are completely sealed with no moving parts and require little maintenance.

3) Massecuite diluter

Principle of the process

A conditioner is normally positioned in the main massecuite pipeline between a crystalliser and centrifugal installation. This type of conditioner is normally designed to work under extreme pressures. Ideally they would be installed close to a cooling crystalliser outlet reducing the pressure loses in the pipe to the continuous centrifugals. In modern sugar factories with high capacity vertical crystallizers high pressures are exerted on sealing arrangements. With the latest development in seals Fives Cail / Fletcher Smith massecuite diluters are now designed to work with 8 bar as a nominal pressure.

Dilutors requires that the mixing molasses used for dilution be diluted and temperature adjusted prior to it being mixed into the massecuite.

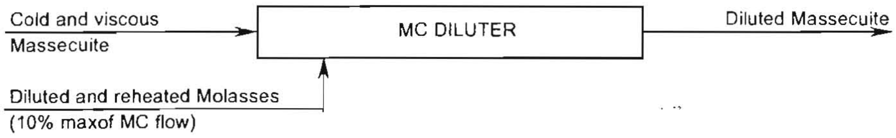


Figure 8 – G. A. of a massecuite diluter

High-pressure massecuite diluters are made up of a cylinder shell that can be installed horizontally or vertically. It is a self-setting device that can be installed in line with an existing massecuite pipeline. The principal of operation is to highly shear the massecuite and the molasses, in order to achieve a perfect homogenization of the product within a very small volume. A cantilever shaft is connected to a motor-reducer on one end, on the rotating shaft there are several rows of four 90° oriented cross blades. In normal operation the rotational speed of the shaft averages 100 rpm. The counter blades connected to the internal shell enhance the mixing of the 2 products. A custom seal allows the conditioner to work under high-pressure massecuite without any leak of mother liquor.

Nominal Diameter (mm)	Installed power (kW)	Rotation speed (rpm)	Massecuite Flow Tm/h	Number of blades / counter blades	Shear Number / revolution
500	30	98	60	12 / 16	96
350	7.5	139	30	6 / 12	36
250	5.5	178	15	6 / 4	12
200	2.2	225	10	4 / 3	8

Figure 9 - Characteristic of Fives Cail / Fletcher Smith high pressure massecuite dilute

VERTICAL SETTINGS

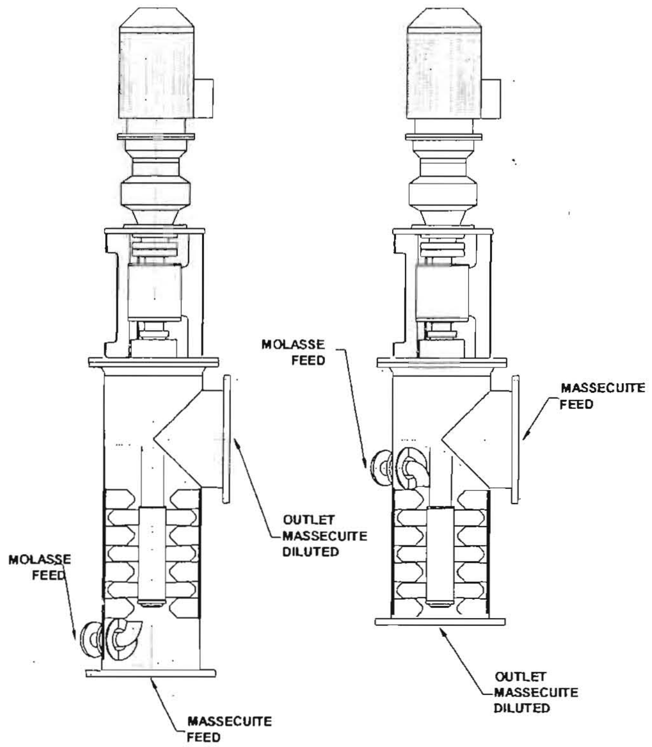


Figure 10 - General arrangement drawing of a Fives Cail diluter

The advantages of mixing/conditioning are the following:

- 2 actions simultaneously, one dilution, one reheating
- Control of the final supersaturation of the final massecuite
- Lower massecuite viscosity. Indeed for the same final mother liquor viscosity, as shown in the comparison table, the massecuite viscosity is much lower than with reheating systems (surface heaters or direct steam injection). The massecuite viscosity can be decreased up to 30%.
- The massecuite temperature (at 50°C max) and the molasses temperature (at 60°C max) remain low, which can be an advantage in relation with the storage of this by-product.

Some specific disadvantages remain:

- Necessity of a powerful and efficient mixer, which absorbs electrical power.
- A control system is necessary. The control system is based on the following 2 principles:
  1. The molasses temperature and dry matter shall be maintained constant.
  2. The flow of molasses shall be adjusted according to the intensity absorbed by the diluter motor.
- The quantity of final massecuite to be treated is increased by 7 to 8 %.

4) Re-heating with direct contact steam.

Steam heating is undertaken by introducing steam directly into the flow of massecuite entering the centrifugal. The most critical step of this operation is the efficiency of the mixing between the steam and the massecuite. Because of the high massecuite viscosity it is not easy to mix with any product, and in particular with steam. A specific mechanical device is generally needed in order to insure a homogeneous mixing. Figure 11 shows the effect of steam mixing with massecuite. There will be thermal losses attributed to this method, as often experienced as indicated on Figure 11.

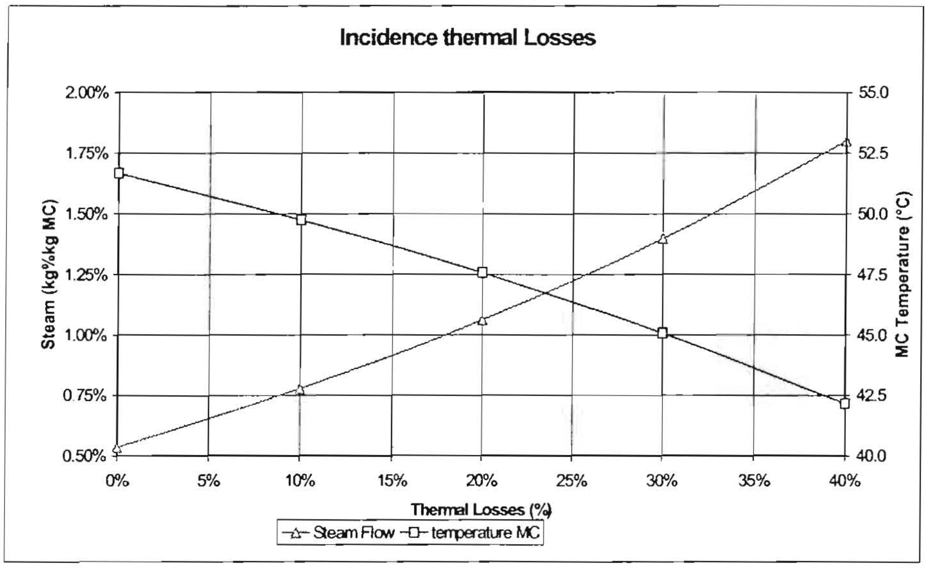
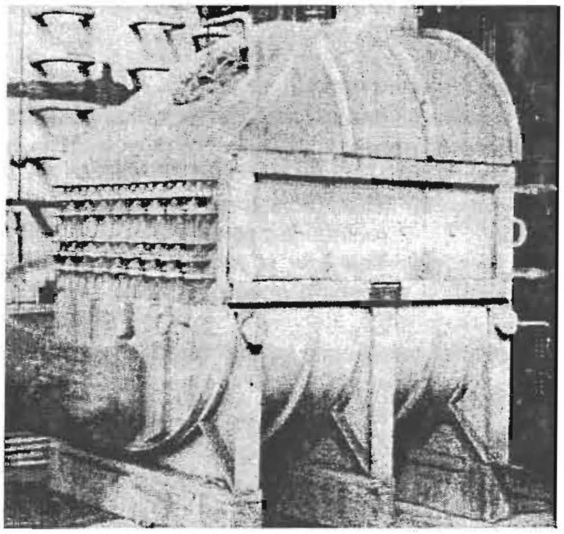


Figure 11 - Incidence of the thermal losses on the performance of the direct steam injection system



		Cooled Massecuite before Conditionning	Massecuite after heating	Molasses	Massecuite after Dilution	Steam	Massecuite after direct injection
Flowrate	mT/h	20.00	20.00	2.18	22.18	0.15	20.15
Brix	%	94.00	94.00	77.00	92.33		93.30
Purity	%	76.00	76.00	59.00	74.61		76.00
Brix of mother liquor	%	89.83	89.83		87.83		88.71
Purity of mother liquor	%	57.43	57.43		57.65		57.43
Crystal content	%	41.00	41.00		36.97		40.70
Temperature	°C	45.0	60.6	80.0	49.7	115.0	54.3
Pressure	bar A					1.69	
Cp	kJ/kg.K	1.7	1.8	2.5	1.8		1.8
Energy	kW	428	600	121	549	112	540
Supersaturation		1.26	1.07	0.48	1.09	0.00	1.08
Viscosity of mother liquor	Poise	1 003	150	0.5	150		150
Viscosity of massecuite	Poise	13 872	2 100		1 370		2 041

Adding lubrication and steam direct to the massecuite just before centrifuging

Figure - 11

	HS/V ratio M sq/M cu	Retention time Minutes	Power requirements	Energy required kJ/kg
Crystalliser Heating	1.3	720	7.5Kw to drive the additional crystalliser capacity agitator. Also a requirement for the hot water pumping.	18
Finned Heater	105	20	7 Kw to drive a water pump for a 23 tph water circulating system	18
Molasses Dilution	nil	5 sec's	6 Kw drive for the conditioner paddle drive.	6
Direct Heating	nil	1 sec's	nil	1

Figure 12 - Summary of results

	Advantages	Disadvantages
Crystalliser Re-heating	Possible phased factory upgrades.	Small heating surfaces to volume ratio. Need high input levels of management, long lag times for a control system. Good instrumentation control required. Risk of localised over heating.
Finned tube Re-heating	No moving parts, totally sealed. Large heating surface to volume ratio.	Instrumentation to control water temperatures.
Inline conditioning	Can be installed into confined spaces.	Moving parts. Additional 7 – 8% loading on the centrifugal. Conditioning of mixing molasses. High degree of instrumentation.
Direct heating	Simple to install. Often provided by the centrifugal supplier.	High risk of crystal losses and purity rise. Difficult to control, when mass flows vary.

An interesting feature with centrifugal should also to be considered before conditioning massecuite. This feature is basket angle to suit different grades of massecuite. Even though most of the centrifugal suppliers propose only one basket angle for standardisation of their production, it is not hard to understand that if a basket angle is well adapted to treat a given massecuite (say B massecuite for a 30° angle basket) with specific characteristics (temperature, purity, crystal size, etc), it will be much harder to work with the same basket on a massecuite with smaller crystal, lower temperature, and higher viscosity such as low grade massecuite. In this case, a massecuite conditioning will be required to achieve good crystal separation

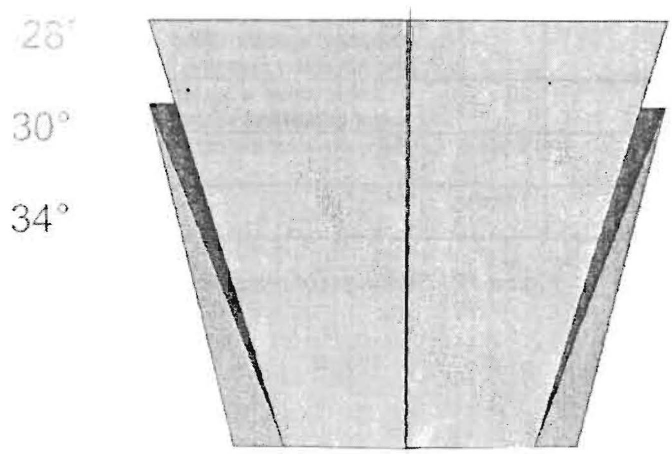


Figure 14 - Relative geometry of continuous centrifugal basket

Conclusion

All of the systems achieve the desired result of reducing the mother liquor supersaturation and they all have their merits and disadvantages. One would have to decide what would be the most suitable for there particular installation.

References

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