C MASSECUITE RE-HEATING USING MICROWAVES

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ABSTRACT

C massecuite processing is an important step in the cane sugar milling process. Massecuite, discharged from vacuum pans, is cooled in cooling crystallizers in order to crystallize the maximum amount of sucrose possible. The high viscosity of massecuite at low temperatures makes purging in continuous centrifugals difficult, and massecuite must be re-heated before the centrifugation step. In order to avoid sucrose dissolution in molasses, this re-heating must be done as quickly as possible. Normally this operation is executed in heat exchangers using hot water. This process has some disadvantages: a long residence time, around 30 minutes, the possibility of massecuite channeling, the possibility of water leaking into the massecuite, and the large area footprint of the equipment. Microwave technology can be an answer to increase the efficiency of this operation. With this technology, massecuite can be heated in a small piece of equipment in a fraction of a minute, with the advantage of no heating water. Also, as there are no heating surfaces, localized hot zones do not occur, avoiding sugar dissolution and massecuite channeling. Heating is uniform throughout the liquid phase. This heating process was tested using a 5 kW continuous microwave system at North Carolina State University. Results of these tests indicate that microwave heating can be used to re-heat massecuite between cooling crystallizers and centrifugal machines without altering the massecuite characteristics.

INTRODUCTION AND MATERIALS AND METHODS

Low grade crystallization is an important step in sugar processing. As much sucrose must be recovered in molasses as possible in order to achieve a factory yield as close as possible to the theoretical one. Crystallization of C massecuite is undertaken, in the first stage, in vacuum pans, and the second part is performed in cooling crystallizers. In this operation, massecuite temperature is lowered allowing crystals to grow by further crystallization. After maximization of sugar crystal content in the massecuite, the temperature is raised to enable efficient centrifugation operation. This temperature must be high enough to decrease the molasses viscosity, allowing it to purge through the screen holes. However, this temperature must not be too high, to avoid sucrose melting. This operation must be quick and well-controlled in order to avoid sugar dissolution into molasses.

In normal operation, C massecuite is heated in large heat exchangers using hot water. In some mills, further heating is undertaken in the centrifugal distributor. This re-heating process has some disadvantages: high residence time, usually more than an hour and sometimes as much as 5 h, the possibility of massecuite channeling, the possibility of water leaking into the massecuite, and large equipment occupying a large area.

Microwave technology may be a more efficient alternative for this re-heating operation. In fact, with microwaves, massecuite can be heated in a fraction of a minute, equipment is of small size, and no other fluid is used for heating. Also, the molasses, with higher water content, is preferentially heated rather than the crystal. This fact will reduce sucrose dissolution with this heating system.

Microwave heating

Utilization of microwave heating for industrial application was conceived about sixty years ago (Metaxas and Meredith, 1983). In the sugar industry, it has been used as a heating tool to dry sugar cubes (Torringa and Neijnens, 2001). An important material characteristic in the application of microwave heating is the dielectric property of the material to be heated. Dielectric properties of molasses collected from all Louisiana mills were measured at 915 MHz. It was observed that dielectric properties are very similar for all Louisiana molasses. Variations in dielectric constant and dielectric loss with temperature are presented in Figure 1.

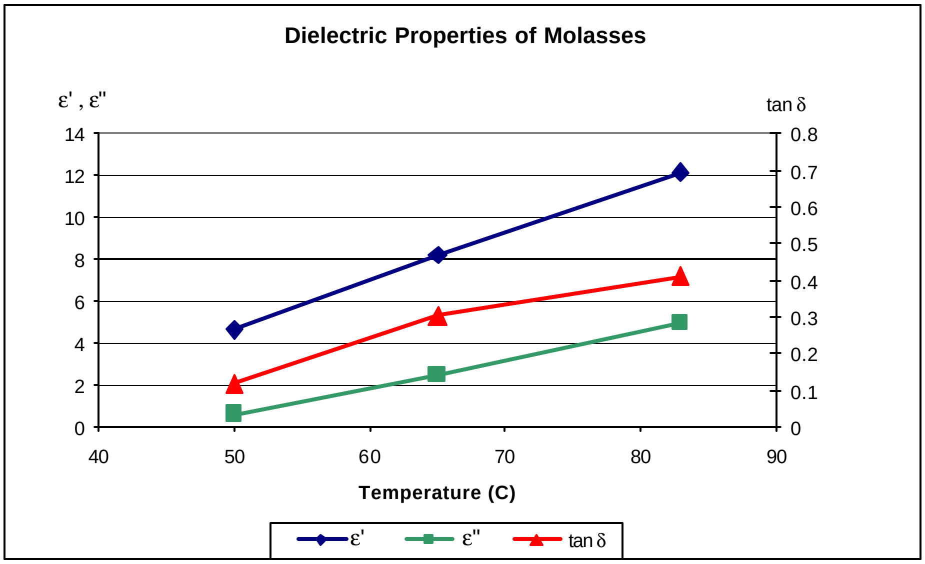

Figure 1. Dielectric properties of molasses.

In Figure 1, ε' represents the dielectric constant of the material, and characterizes the ability of the material to absorb microwave energy; ε" is the dielectric loss; and tan δ is the ratio of ε"/ε'. Figure 2 presents the dielectric properties of a synthetic massecuite (a mixture of raw sugar, dextrose, and molasses).

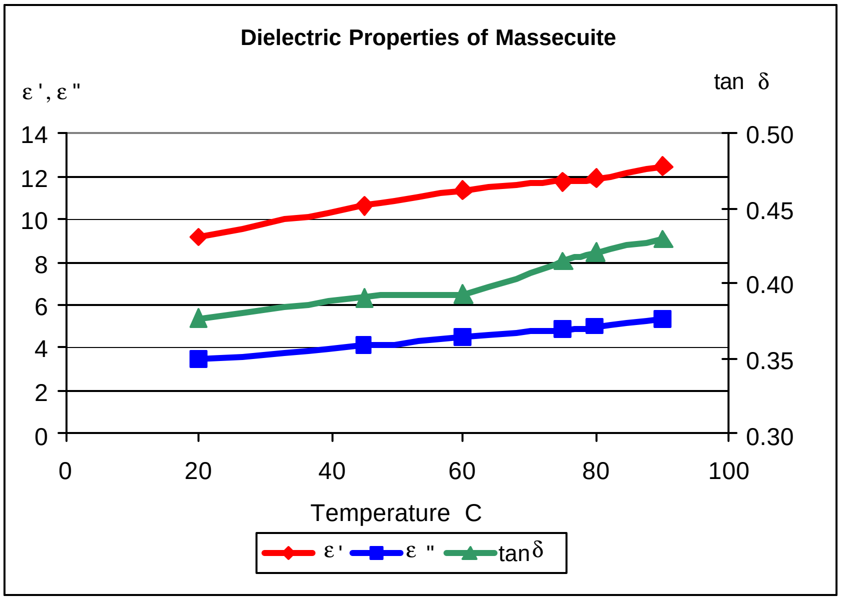

Figure 2. Dielectric properties of synthetic massecuite @ 95°Bx.

Table 1 compares the dielectric properties of molasses with those of other food products. Water has a dielectric constant, ε’, 15 times higher than molasses, which means that water will absorb more microwave energy than molasses. Water is also more likely to convert this microwave energy into heat as compared to molasses; the dielectric loss of water is four times higher than the dielectric loss of molasses. According to these values, and compared with molasses, massecuite has a higher capacity to absorb microwave energy but presents a higher relative dielectric loss.

Another important parameter with practical interest is the radiation penetration depth in the material. Applying the equation described by von Hippel (Mudgett, 1982), this parameter was determined to be 40.4 cm and 8.1 cm for molasses and massecuite, respectively. Therefore, a maximum diameter pipe of 16 cm must be used for massecuite heating.

The purpose of massecuite re-heating is to raise the temperature of cooled massecuite from about 38 °C to about 54 °C. Although the dielectric properties of massecuite are not ideal, it was believed still that microwave technology could be used for massecuite re-heating. This was tested using laboratory scale microwave equipment available at NCSU (North Carolina State University) (Figure 3). The paper presented by Coronel et al., 1981, describes the microwave equipment. The schematic representation of the microwave system is presented in Figure 4.

RESULTS

A synthetic massecuite was prepared using a mixture of raw sugar, dextrose and final molasses. Dextrose was used to obtain a product with purity similar to C massecuite. Analyses of molasses and the raw sugar/dextrose mixture are presented in Table 2.

Table 1. Comparison of dielectric properties of molasses with other materials.

	T °C	**MHz**	**e'**	**e''**	**Tan** d
Water	50	915	70.4	2.11	0.03
Carrot (1)	50	915	65	28	0.43
Potato (2)	50	915	58	39	0.67
Beef (3)	50	915	55	39	0.71
Pork (3)	50	915	52	38	0.73
Massecuite (4)	60	915	11.4	4.5	0.39
Molasses	50	915	4.63	0.55	0.12
Butter (5)	35	2,450	4.15	0.44	0.11

(1) Bengtsson and Risman ,1971 (ref. in Mudgett, 1982)
(2) Ohlsson *et al*., 1974 (ref. in Mudgett, 1982)
(3) To *et al*., 1974 (ref. in Mudgett, 1982)
(4) Mixture of raw sugar/molasses/dextrose @ 95 °Bx
(5) Ref. in Metaxas and Meredith, 1983

Figure 3. Microwave equipment at NCSU.

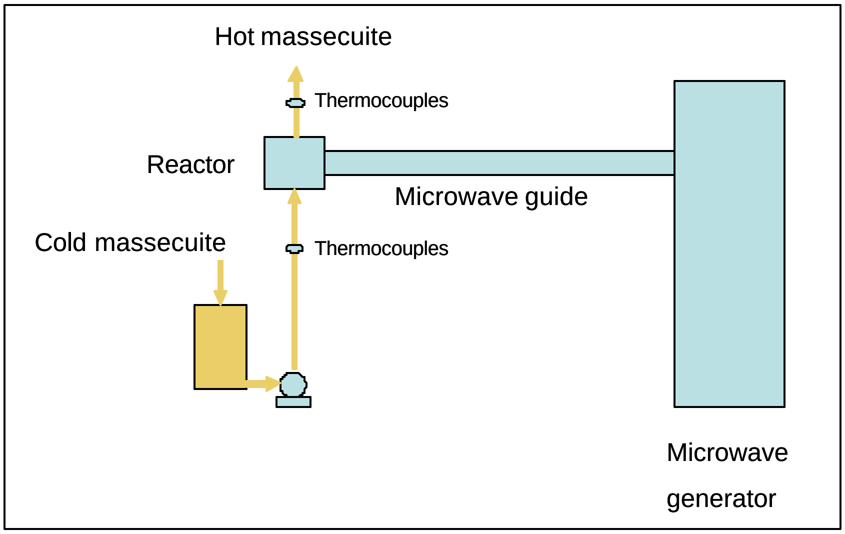

Figure 4. Schematic diagram of microwave system used.

Table 2. Analysis of molasses and sugar.

	Molasses	**Raw sugar + dextrose**
Brix	82.8	
Moisture		0.28
Pol ^{o}		98.9
Purity	30.5	
Sucrose*	33.9	
Glucose*	4.63	6.19
Fructose*	9.16	0.18
Ash*	15.2	0.35
Color IU		2,050

* g/100g sample

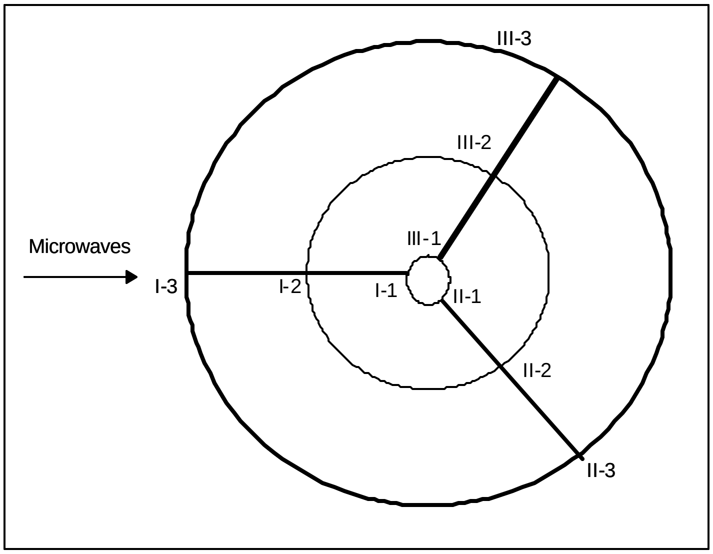

Figure 5. Array of thermocouples for temperature distribution.

Three tests were run with the 5 kW microwave equipment at NCSU. Massecuite was pumped in up-flow through a 38 mm pipe through the reactor. At the reactor outlet, an array of thermocouples was installed to determine the cross sectional temperature distribution. Three thermocouples were placed in the center (2 mm from the center); three in the middle (5 mm apart), and three in the periphery (5 mm apart) (Figure 5).

Table 3. Variation of massecuite properties with microwave heating.

	TRIAL 1		**TRIAL 2**		**TRIAL 3**	
	In	**Out**	**In**	**Out**	**In**	**Out**
Brix	95.27	95.65	92.51	92.32	91.26	91.78
App.Purity	81.31	82.50	71.12	71.23	69.51	70.28
Sucrose *	78.46	79.13	68.12	67.40	64.73	66.48
Glucose *	5.45	5.50	5.20	5.17	5.49	5.31
Fructose*	2.55	2.47	5.49	5.31	4.35	4.14
Ash *	4.58	4.47	7.10	7.05	7.44	7.21
Color IU	33,400	33,300	59,000	67,800	66,300	65,800

* g/100g massecuite

Massecuite properties before and after processing are presented in Table 3. It can be seen that the characteristics of the original mixture, used in Trial 1, did not change significantly after the microwave heating. In Trials 2 and 3, the massecuite from Trial 1 was re-used, after adding molasses to reduce the brix value.

Trial 1:

In this test, the temperature of cool massecuite, between 41 and 48 ^{o}C, was raised to average temperatures of 63, 57 and 83 ^{o}C (Figure 6). This figure also presents the microwave net power applied to the massecuite. The net power is the power corresponding to the fraction of microwaves that is absorbed by the massecuite and converted into heat. The excess energy is deflected to a water container where it is absorbed to protect the generator. In this trial, between 510 and 984 seconds after start (Trial 1-A), a stable condition was obtained with an average outlet massecuite temperature of 63 ^{o}C, and an inlet average temperature of 44.5 ^{o}C (Figure 7). A net power of 470 watts was used during this period. Due to the location of the thermocouples and the low flow rates, there is a time delay between inlet and outlet temperature readings and power applied.

Table 4 presents the temperatures of each sensor placed in the outlet pipe. Sensor II 2 was not working properly. As it is observed, a maximum temperature difference of 3.7 ^{o}C was registered within the massecuite.

Table 4. Trial 1-A: Temperatures of heated massecuite in °C.

Sensors	**I**	**II**	**III**	**Average**	**D maximum**
Interior	**65.2**	**61.7**	**61.6**	**62.8**	**2.6**
Middle	**63.6**	**N/A**	**62.6**	**63.1**	**1.0**
Outside	**61.5**	**63.8**	**63.5**	**62.9**	**2.3**
Average	**63.4**	**62.8**	**63.5**	**62.9**	
D maximum	**3.7**	**2.1**	**1.9**		**3.7**

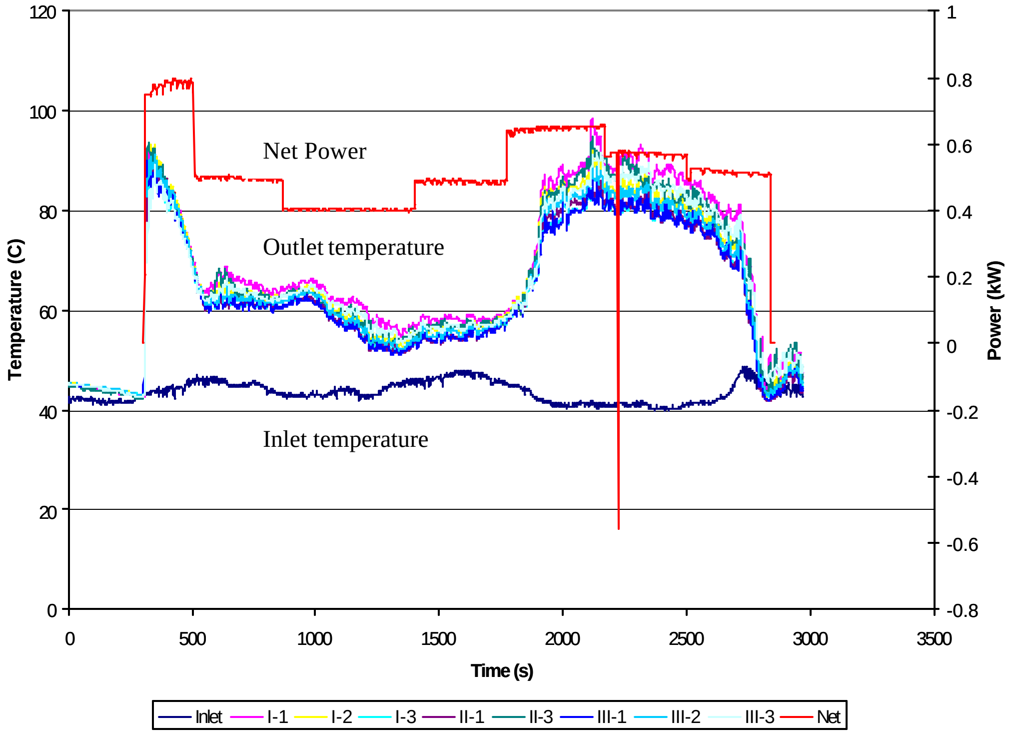

Figure 6. Trial 1-A: Temperatures of massecuite in and out, and net power.

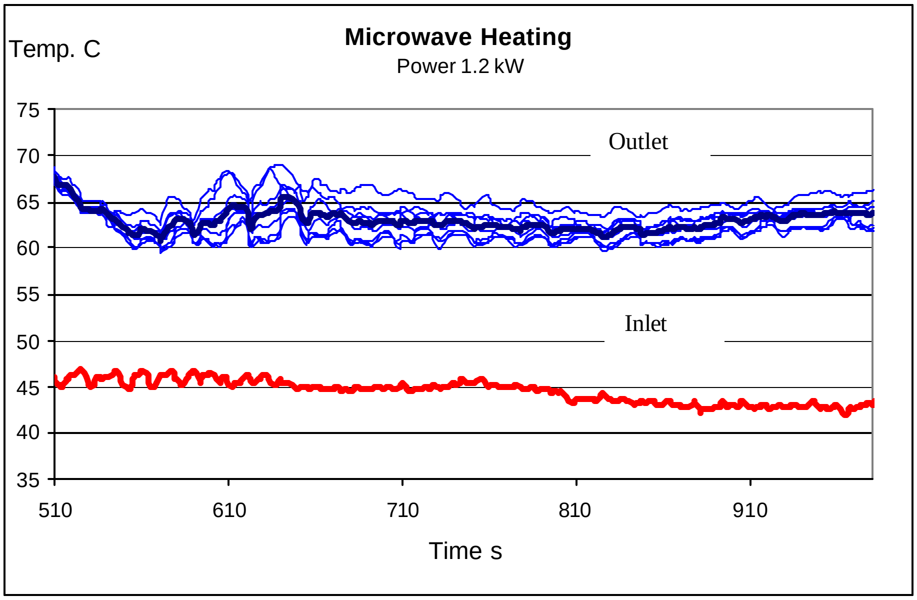

Figure 7. Trial 1-A: Inlet and outlet (average in bold) massecuite temperatures.

Between 984 and 1,600 seconds, the power applied was reduced to a net power of 430 watts, in order to decrease the outlet temperature (Trial 1-B) (Figure 8). A mean temperature of 56.6 ^{o}C at the outlet was observed, with an average inlet temperature of 44.3 ^{o}C. The temperatures of each sensor are presented in Table 5 and average temperatures are presented in Figure 8.

Between 1,900 and 2,170 seconds from start, the power supply was increased to 650 watts of net power and then decreased to 570 watts until 2,500 seconds (Trial 1-C). A mean temperature of 83.2 °C in the outlet massecuite was observed, with an average inlet temperature of 40.9 °C. The temperatures of each sensor are presented in Table 6 and average temperatures are presented in Figure 9.

Table 5. Trial 1-B: Temperature of heated massecuite in °C.

Sensors	**I**	**II**	**III**	**Average**	D **maximum**
Interior	**59.3**	**55.0**	**55.0**	**56.4**	**4.3**
Middle	**57.1**	**N/A**	**56.2**	**56.7**	**0.9**
Outside	**55.2**	**57.4**	**57.8**	**56.8**	**2.6**
Average	**57.2**	**56.2**	**56.3**	**56.6**	
D **maximum**	**4.1**	**2.4**	**2.8**		**4.3**

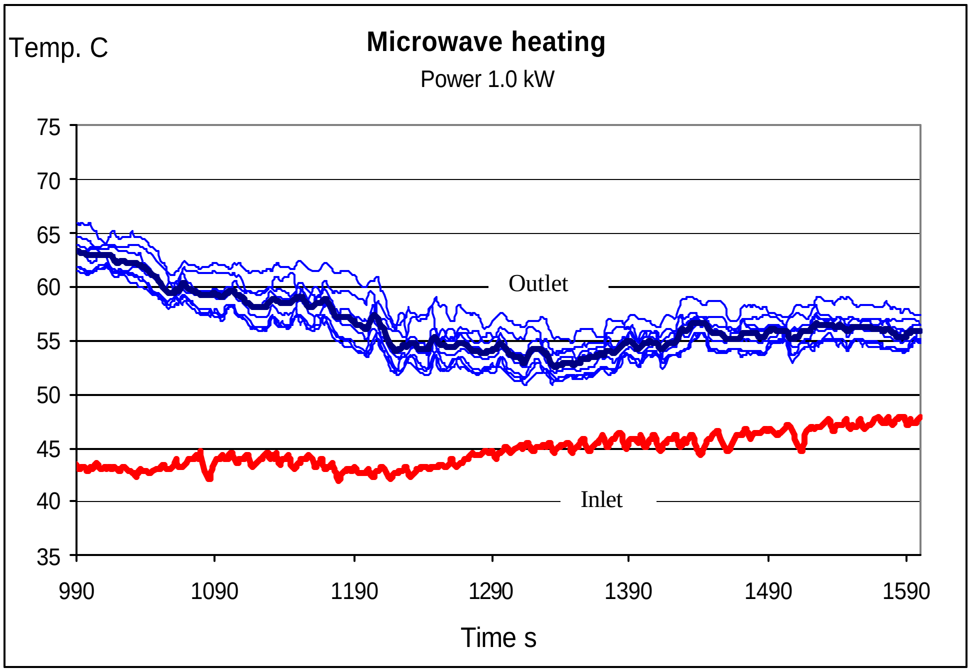

Figure 8. Trial 1-B: Inlet and outlet (average in bold) massecuite temperatures.

At the middle of Trial 1, it was observed that the inlet temperature increased to 48 °C. This heating, due to pumping effort of the high viscosity massecuite, was reduced by cooling the feed pipe with cold water.

Table 6. Trial 1-C: Temperature of heated massecuite in °C.

Sensors	I	II	III	Average	D maximum
Interior	**88.4**	**80.6**	**79.7**	**82.9**	**8.7**
Middle	**84.4**	**N/A**	**82.4**	**83.4**	**2.0**
Outside	**79.6**	**85.8**	**84.9**	**83.4**	**6.2**
Average	**84.1**	**83.2**	**82.3**	**83.2**	
D **maximum**	**8.8**	**5.2**	**5.2**		**8.8**

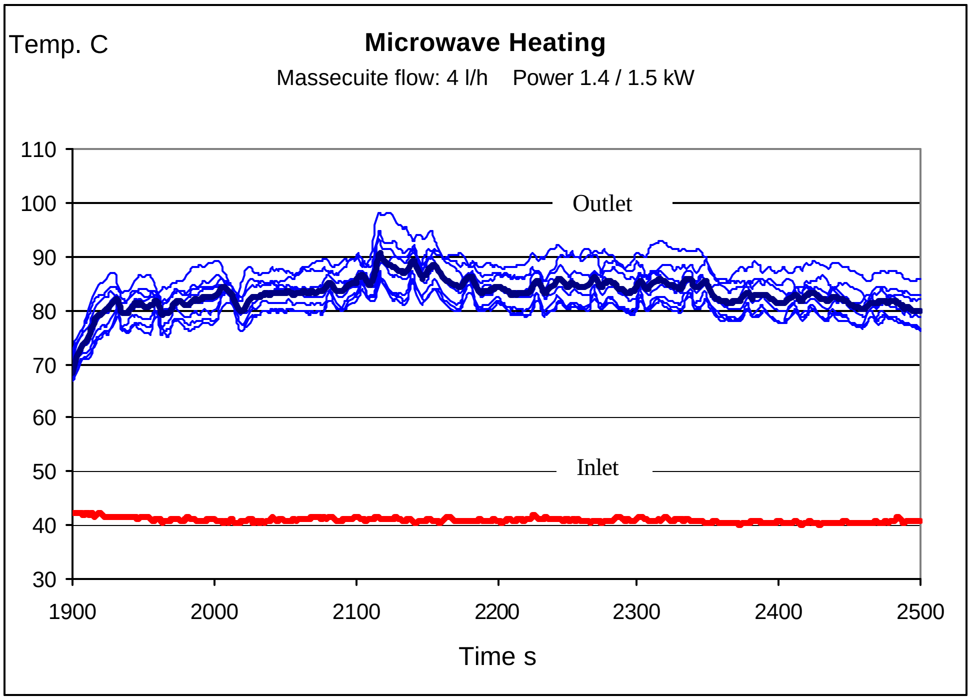

Figure 9. Trial 1-C: Inlet and outlet (average in bold) massecuite temperatures.

Trial 2:

Due to the extra heating and the low flow rates caused by massecuite viscosity, it was decided to decrease the massecuite brix for the second trial. Brix was lowered from 95° to 92° and flow rates increased from 4 to 21 liter/hour. In this trial, a total power of 2,200 watts was applied. With a feed temperature of 31.1 °C, and a flow rate of 21 l/h, outlet massecuite average temperature was 42.1 °C (Figure 10). In this period, the maximum temperature difference recorded in the outlet massecuite was 13.0 °C.

During this trial, net power was not recorded, and the aluminum stubs were adjusted. These stubs, placed in the wave guide between the generator and the reactor, can change the microwave distribution in the reactor and can increase energy absorption in the reactor.

Table 7. Trial 2: Temperature of heated massecuite in °C.

Sensors	I	II	III	Average	D maximum
Interior	**41.4**	**39.3**	**40.0**	**40.2**	**2.1**
Middle	**38.5**	**N/A**	**41.9**	**40.2**	**3.4**
Outside	**37.5**	**50.5**	**47.8**	**45.2**	**13.0**
Average	**39.1**	**44.9**	**43.2**	**42.1**	
D maximum	**3.9**	**11.2**	**7.8**		**13.0**

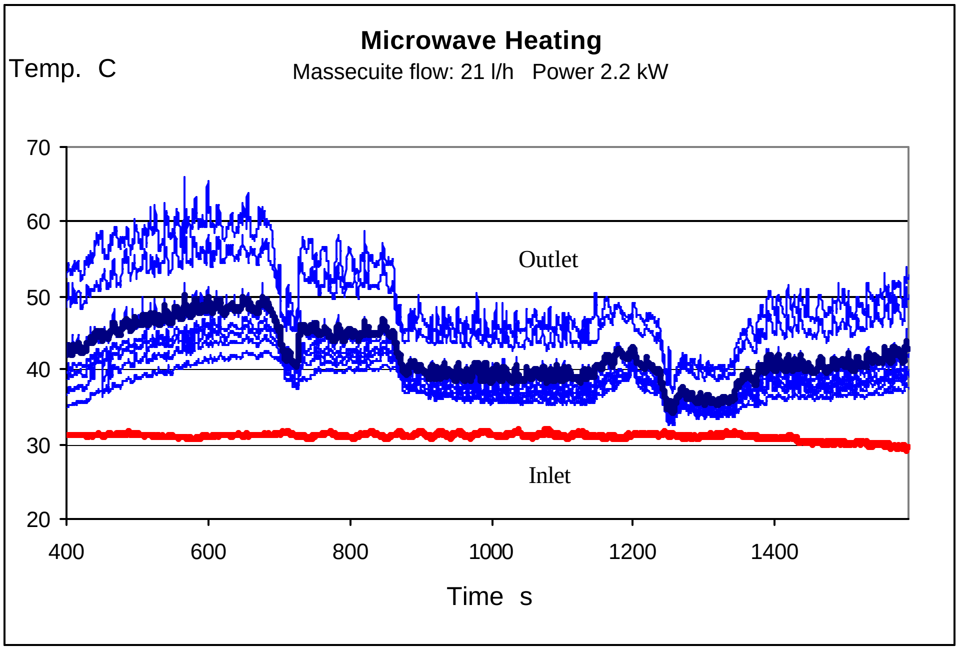

Figure 10. Trial 2: Inlet and outlet (average in bold) massecuite temperatures.

Trial 3:

In order to increase the feed flow rate, massecuite brix was further decreased to 91° for the third trial. Flow rates of 32 and 42 l/h were obtained. Applying a power of 2.2 kW, the massecuite was heated from 35.2 to 66.4 °C at 32 l/h (Trial 3-A; till 600 seconds) and from 35.9 to 51.5 °C at 42 l/h (Trial 3-B) on average (Tables 8 and 9; Figure 11).

Table 8. Trial 3-A: Temperature of heated massecuite in °C.

Sensors	I	II	III	Average	D maximum
Interior	**66.8**	**67.8**	**68.4**	**67.6**	**1.6**
Middle	**66.5**	**N/A**	**68.2**	**67.4**	**1.7**
Outside	**63.0**	**64.0**	**66.6**	**64.5**	**3.6**
Average	**65.4**	**65.9**	**67.7**	**66.4**	
D maximum	**3.8**	**3.8**	**1.8**		**5.4**

Table 9. Trial 3-B: Temperature of heated massecuite in °C.

Sensors	I	II	III	Average	D maximum
Interior	**51.7**	**51.2**	**51.7**	**51.5**	**0.5**
Middle	**50.2**	**N/A**	**50.9**	**50.9**	**0.7**
Outside	**49.2**	**55.7**	**51.8**	**51.8**	**6.5**
Average	**50.4**	**53.5**	**51.2**	**51.5**	
D maximum	**2.5**	**4.5**	**0.9**		**6.5**

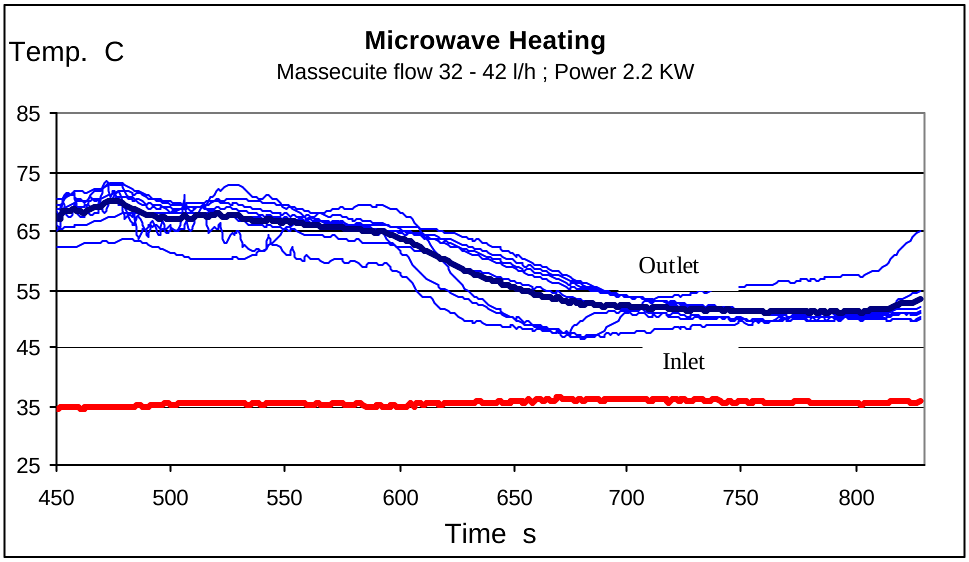

Figure 11. Trial 3: Inlet and outlet (average in bold) massecuite temperatures.

The results of these trials are summarized in Table 10.

Table 10. Results of the trials of massecuite microwave heating.

		TRIALS					
		1 - A	**1 - B**	**1 - C**	**2**	**3 - A**	**3 - B**
Massecuite	**Brix**	95.3	95.3	95.3	92.5	91.3	91.3
	Flow l/h	-	-	4	21	32	42
	Temperature (°C) - in	44.5	44.3	40.9	31.1	35.2	35.9
	Temperature (°C) - out	62.9	56.6	83.2	42.1	66.4	51.8
	DT °C (out-in)	18.4	12.3	42.3	11	31.2	15.9
	DT max. (sensors) °C	3.7	4.3	8.8	13.0	5.4	6.5
	Residence time (min)	-	-	2.1	0.4	0.3	0.2
Energy	**Total Power kW**	1.2	1.0	1.5/1.4	2.2	2.2	2.2
	Specific energy W.h/kg	-	-	238	70	46	35
	Energy W.h/kg/ DT °C	-	-	5.6	6.4	1.5	2.2

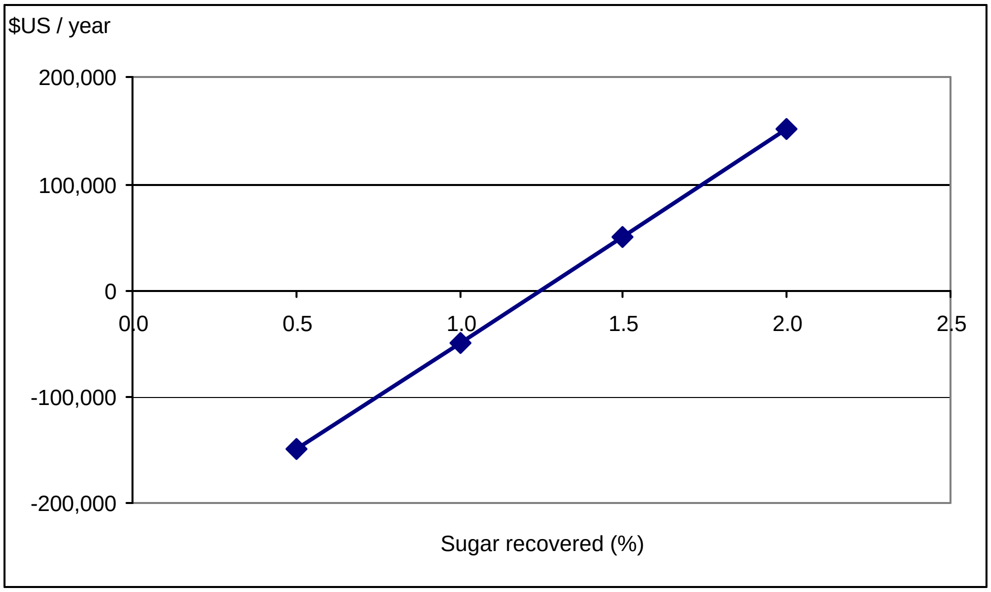

Figure 12. Annual savings due to extra sugar recovered from C massecuite.

ECONOMIC BALANCE AND CONCLUSIONS

In a typical sugar mill, a flow of 20 tons/h of C massecuite must be heated from 38 to 54 ^{o}C (100 to 130 ^{o}F). Considering a specific energy consumption of 2.2 W.h/(kg.°C), the energy requirement will be 704 kW.h. Deducting the theoretical energy required, 166 kW.h, the excess energy used by microwaves will be 538 kW.h, which corresponds to a cost of $103,300 per season (@ $0.08/kWh). Figure 12 presents the savings per season achieved with this system according to the percentage of extra sugar recovered when microwave heating is used. This process will be economically viable for values of sugar recovery higher than 1.5 %, on massecuite solids (representing $140,500 of net profit per season). A sugar price of $0.20/lb was assumed, and capital and maintenance costs were included. For a mill with a daily capacity of 10,000 ton of sugar cane, the cost of the microwave equipment is around $700,000.

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The following conclusions can be drawn from these trials:

- Rapid microwave heating can be used to re-heat the massecuite between cooling crystallizers and centrifugal machines.
- Microwave heating does not significantly alter the massecuite characteristics.
- A uniform temperature distribution in the massecuite can be achieved.

To achieve a uniform massecuite temperature in practice, it will be necessary to develop a system that compensates for the variation in massecuite flow.

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