Novel process for the drying of sugar cubes applying microwave technology

H.M. TORRINGA[1], H.P.M NEIJNENS[2]
1. Agrotechnological Research Institute, P.O. Box 17, 6700 AA, Wageningen, The Netherlands
2. Aquarius Machinefabriek BV, P.O. Box 296, 6000 AG, Weert, The Netherlands

ABSTRACT

Drying of sugarcubes is traditionally performed with long-wave ceramic infrared heating elements. These drying units including a cooling section have a length of about 50 m, a drying/cooling time of 12 minutes with a throughput of 1600 kg/h. Required final moisture content is 0.4% (wet basis) and water evaporation required is 10 – 15 kg/h. The infrared drying unit has a low rate of heating up (max. 6 °C/min) and a low thermal efficiency (38%). A feasibility study has been carried out applying microwave heating at a frequency of 2450 MHz and radio-frequency heating at a frequency of 27.15 MHz. These techniques together with infrared drying are evaluated with respect to drying performance and quality characteristics. The newly developed microwave drying process has been patented and several units are implemented on an industrial scale. In the paper the entire sequence from feasibility study to commercialisation is described.

INTRODUCTION

Aquarius Machine Factory, Weert, The Netherlands constructs among other things integrated systems for the production of sugar cubes. A production line consists of a unit for compression of sugar-water mixture to cubes, a drying section and a packing system, see *figure 1*.

In general sugar cubes are dried applying infrared heating. The energy density of the infrared radiation is high, so an effective surface evaporation can be obtained. However, the penetration depth is rather small and most heating up occurs via conduction from surface to centre of the cube. This strong dependence on conduction results in significant temperature gradients with the consequence that diffusion from the innerpart of the cube to the surface is limited.

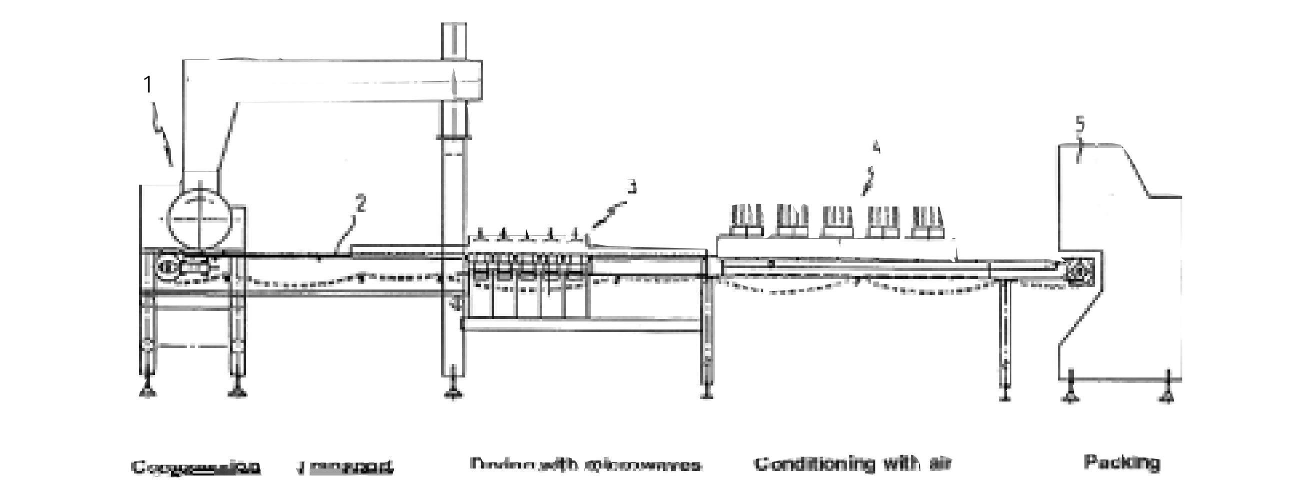

Figure 1: Schematic drawing of sugar cube production unit.

The market for sugar cube production units is especially attractive with respect to the replacement market. Many units operate with outdated technology and could be replaced or updated. If the production figures for sugar cubes are studied (see *table 1*), the outcome is that the yearly sugar cube consumption of the inhabitants of the mentioned countries is considerable.

Table 1: Consumption figures of sugar cubes of several European countries in 1995.

Country	daily production (10^3 kg)	annual production (10^3 kg)	annual production per inhabitant (kg/person)
Netherlands	250	62.500	4.1
Belgium	250	62.500	6.2
France	1200	300.000	5.2
Germany	600	150.000	1.9
United Kingdom	100	25.000	0.4

If it is assumed that all produced sugar is consumed in the country of production, the figures indicate that several kg of sugar cubes are consumed by an inhabitant per year, for instance a Dutch person consumes more than 3 sugar cubes per day per person. From the assumption that a unit produces about 25 tons sugarcubes per day, it can be concluded that approximately 100 units are operational in the mentioned countries.
The motivation for innovating the infrared drying process is:
- low volume averaged heating rate
- low drying rate
- high energyconsumption/low thermal efficiency
- large dimensions of the infrared dryer

APPROACH

The objective of the feasibility study is to assess the technical and economical feasibility of microwave and/or radio-frequency drying. The approach of the project is:
- comparison of different drying techniques with respect to temperature profiles, drying curves and energy consumption: microwave, radio-frequency and infrared drying
- quality assessment of dried product with respect to colour, hardness, corner strength and solubility
- assessment of temperature sensitivity of the product, determination of maximum acceptable product temperatures
- economical evaluation of estimated investment costs and necessary installed power

The drying experiments are carried out at pilot plant scale with the following characteristics:
- microwave continuous conveyor belt dryer, operating frequency 2450 MHz, power 6 kW
- radio-frequency batch unit, operating frequency 27.15 MHz, power 7 kW
- infrared conveyor belt dryer, short and medium wave emitters, power 10 kW

During drying the weight loss was measured from taking out sugarcubes and determining moisture content with a polarimeter. Temperature inside the cube with fluoroptic thermocouples, incident and reflected power with an HP-Spinner couple and absorbed electric power with a standard measuring device.

Quality evaluation was performed using:
- Minolta Hunter L,a,b meter for colour, L value is a measurement for the whiteness of the cube
- Q-tester for cornerstrength measurement, rotating the cubes for a specific time at specific rotation velocity in a box and measure the weight of the bigger parts
- a beaker with water and a metal mesh sugar cube holder to determine the solubility time for the sugar cube to dissolve in water of 35 °C with a magnetic stirrer at 200 RPM
- Instron universal compression unit to determine hardness and breaking strength from compression with a flat element at 50 mm/min

RESULTS

Drying curves

The drying curves are shown in *figure 2* for microwave, radio-frequency and infrared drying. The power density for the different drying techniques is based on the electromagnetic power put into the drying process. The initial moisture content of the sugarcube after the pressing procedure is in between 1 and 1.5% moisture. The minimum drying time for microwave heating is 4 minutes, for radio-frequency treatment 5 minutes and for infrared heating a minimum drying time of 8 minutes, which is exactly the drying time of an industrial system. Based on the drying curves, the drying time can be decreased maximally with 50%.

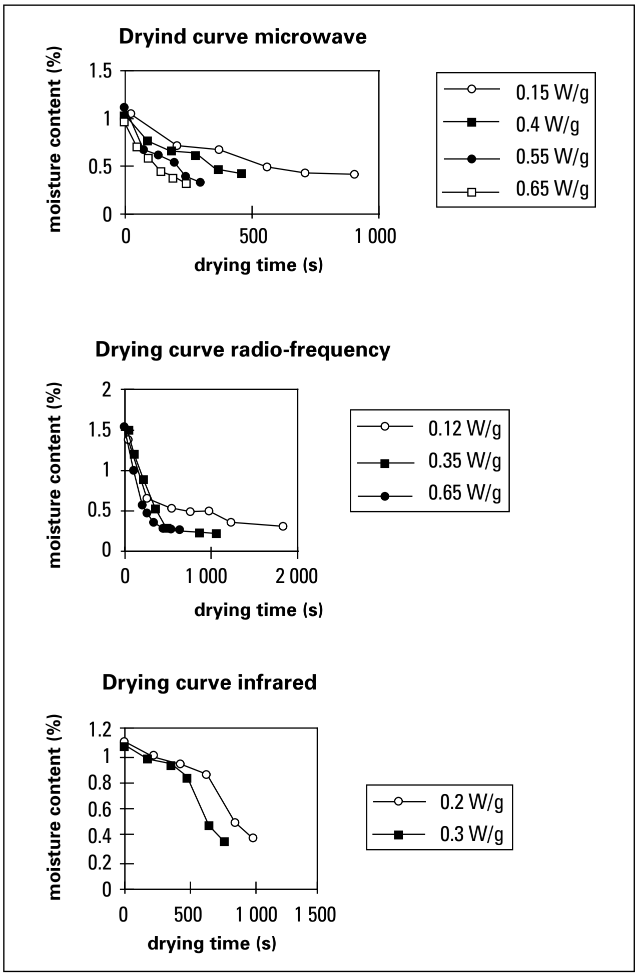

Figure 2: Drying curves of the different drying techniques.

Temperature profiles

In *figure 3* the temperature profiles are shown for microwave, radio-frequency and infrared drying.

All temperatures are measured in the centre of the cube during processing. The heating up with microwaves or radio-frequency energy gives a much higher heating rate compared to infrared heating. The maximum heating rate with micowave and radio-frequency drying is 25 °C/min. and for infrared drying 6 °C/min. The penetration depth of infrared energy is much smaller than the thickness of the cube, while the penetration depths of microwave and radio-frequency heating are larger than the dimensions of the sugar cube. If the absorbed power is studied as a function of maximum reached temperatures and related to drying time, it can be concluded that using a power higher than 0.5 W/g gives significant higher product temperatures, but only slightly shorter drying times. Further experimenting showed that heating till a temperature of approximately 75 °C is sufficient for evaporation of the remaining moisture within the product. The latent heat in the volumetric heated cube is sufficient for the evaporation till final moisture content.

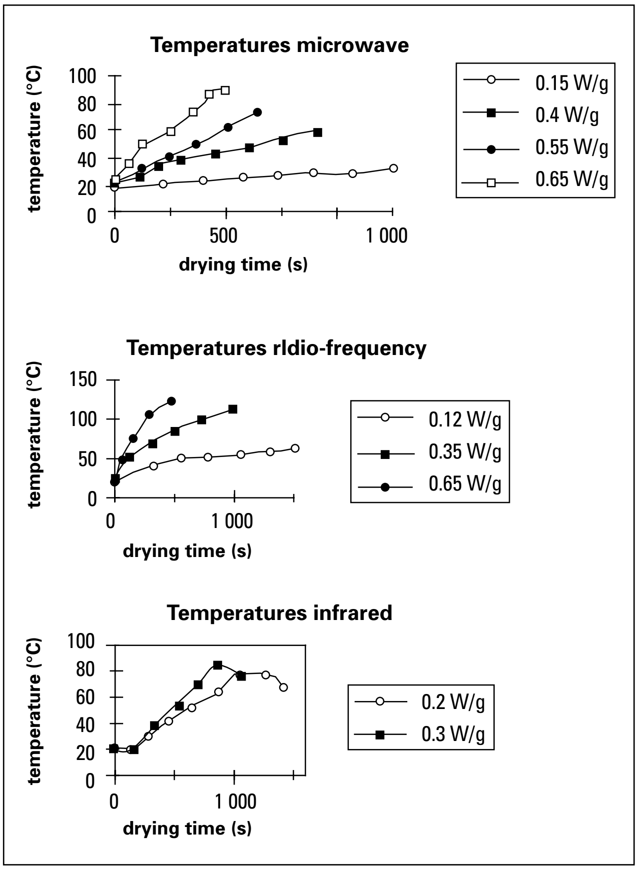

Figure 3: Temperature profiles of sugar cubes for the different drying techniques.

Colour

The colour is measured with a tri-stimulus Minolta spectro-colorimeter. Measurements are done in L,a,b mode. The L parameter represents a photometric value giving the total amount of reflected light. This value can be used to quantify the whiteness of a sugar cube. In *table 2* the whiteness of the sugar cubes after microwave, radio-frequency and infrared drying is shown. No differences in colour were observed.

Corner strength

The corner strength of the cubes for the different drying techniques are measured with a Q-tester. The cubes are weighed, put into a metal box and rotated for 2 minutes. Next the sugar cubes are sieved and the parts remaining on the sieve are weighed. The ratio of the part remaining after rotating and the initial weight is the pfost num-

Table 2: Colour values, pfost number and compression properties of sugar cubes dried with different drying techniques.

Microwave Drying				
power density	**L parameter (-) (colour)**	**Pfost number (%) (corner strength)**	**Force at fracture (N) (breaking strength)**	**Slope on compression curve (N) (hardness)**
0.15	41.68	75	150	20
0.4	42.66	76	170	30
0.55	43.52	80	180	35
0.65	43.45	78	190	35
reference cubes	42.62	79	350	50
Radio Frequency Drying				
power density				
0.12	86.7	89	200	30
0.35	86.5	87	175	25
0.65	85.8	85	200	30
reference cubes	86.9	79	350	50
Infrared Drying				
power density				
0.3	90.69	89	400	60
0.2	90.86	85	300	50
reference cubes	90.86	79	350	50

ber and a high number represents relative strong corners of the sugar cubes. In table 2 the results are shown, the corner strength seems to be slightly higher for higher intensity drying with microwaves, but within the reproducibility of the measuring method this increase is not significant. The solid bridges within the sugar cubes are not weaker applying volumetric heating (microwave or radio-frequency) compared to surface heating (infrared), while from common experience it is known that slow dried sugar cubes become harder and stronger.

Mechanical Properties

The mechanical properties are determined with an Instron material compression system. The cube is compressed with a flat plate element with a velocity of 50 mm/min. The force as a function of replacement is recorded and shown in *figure 4*.

The force quickly increases with the element touching the cube and after the breaking of the cube, the force rapidly decreases. The maximum force represents the breaking strength of the cube and the slope the hardness of the cube. These kinds of tests need a lot of repetition, because the weight of the sugar cubes at the same moisture content is slightly different, which means that more material is available in the same size. The standard deviation is 15 N for the maximum breaking force and 10 N/mm for the hardness. In *table 2* the microwave and infrared dried cubes seem to break at higher force and are a bit harder, when dried with higher intensity. The radio-frequency dried cubes, which are more equally dried, are not becoming significantly harder with more intensive drying. Volumetric dried cubes are a bit less hard then infrared dried cubes. The conditioning part after drying increases the strength of the cube and production can be controlled to produce a cube sufficiently strong according to the needs of the customer.

Solubility

The solubility of the sugar cubes is measured with an new developed method. A beaker of 1000 ml is filled with 800 ml water. A metal gauge with a square perforation of 4 mm is put under the water level at the 600 ml tick. The

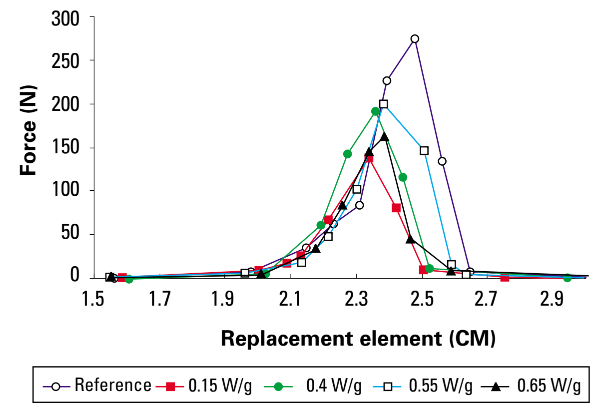

Figure 4: Compression curve for sugar cubes for microwave drying at different intensities.

water is stirred with a magnetic element at 200 RPM. An amount of 6 sugarcubes is put on the gauge and time is measured when all sugar cubes are dissolved. In *table 3* the solubility rate of the sugar cubes is shown. The standard deviation is 0.02 g/s. Radio-frequency dried sugar cubes have a higher solubility rate. This is probably due to the more homogeneous drying compared to microwave and infrared drying resulting in a more homogeneous structure.

Table 3: Solubility of sugar cubes with different drying techniques.

Drying technique	Solubility rate (g/s)
reference, infrared	0.35
microwave	0.35
radio-frequency	0.58

Dimensioning of the drying unit

The approximate dimensions can be calculated from the experimental results. From the experiments the absorbed electromagnetic power is measured. With the conversion efficiency, the supplied electrical power can be calculated. The drying time and the required throughput will give the load in the oven. The dimensions of the oven follow from either product dimensions or dimension of the multiple generators. In this case, the product size is limiting. The installed power is calculated from the load in the oven and the necessary power absorption of the product. Finally the specific energy consumption is assessed. The microwave unit has the smallest dimensions and has the lowest energy consumption.

CONCLUSIONS

The research project has led to a successful technical-economical feasibility of the drying of sugar cubes with microwave or radio-frequency energy. From a constructional and economical point of view an implementation has been proposed applying a multimode, multiple generator input. Motivation for this choice:

- small microwave generators have become cheaper the last 4 years and are attractive in continuous conveyor belt applications
- high electrical field strength necessary for radio-frequency heating, because of the unfavourable dielectric properties of the sugar cube
- the conveyor belt length requires more radio-frequency generators, which is costly

The study shows that the following advantages can be obtained:

- 35 – 50% reduction drying time
- 20 – 40% energy saving depending on the final mechanical properties required of the sugar cube, a harder cube requires more energy input
- 40 - 60% space saving by higher compactness of the unit
- 20% lower product temperatures and more homogeneous heating up
- higher flexibility in production, drying process independent of cube size
- lower electricity peak at start-up
- adjustable hardness, other quality demands can be fulfilled with respect to colour, solubility and corner strength
- improved process control, supply of heat can be termined instantaneously by shutting off microwave power, terminating infrared energy supply causes some after-heating of the cubes

At present Aquarius is producing sugar cube production units applying microwave heating at industrial scale. The first units are utilised in 1998.

Table 4: Dimensioning of the unit.

	microwave unit	infrared unit (Aquarius)	radio-frequency unit
electromagnetic absorbed power (W/kg)	ca. 550	ca. 265	ca. 475
conversion efficiency	0.7	0.5	0.7
electrically supplied power (W/kg)	785	660	680
drying time (min)	3.5	8	5
load in the oven at throughput 1600 kg/h (kg)	95	215	135
amount rows of cubes with 50 cubes in a row and cube weight 3.3 g (-)	575	1300	820
physical length drying unit as a result of the load (m)	10.5	23.5	15.0
required power determined from absorbed power in experimenting (kW)	75	145	95
specific energie consumption unit (Wh/kg)	45	90	55

Acknowledgement

The financial support of the Dutch department for energy and environment with reference to Novem-Mint project 338.320/1080 is greatly acknowledged.

LITERATURE

Derckx, H.A.J.M. and Torringa, H.M. (1997), Unit for the drying of sugarcubes (in dutch), Dutch patent 1006216.