FOAM-MAT DEHYDRATION OF TOMATO PASTE USING MICROWAVE ENERGY

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Preliminary results of the comparative studies of foam-mat dehydration of tomato paste by a conventional hot-air method and a method employing microwave energy are presented. Generation of heat within the product by means of microwave power dissipated in it provides increased rates of dehydration. The foaming of the product provides an increased surface area which increases the dehydration rates, but at the same time, in hot-air dehydration methods, the rates are limited due to a decrease in the thermal conductivity resulting from the presence of the air bubbles in the product. Samples of tomato paste of various thicknesses of 27% solid content and a density of 0.38 g/cm^3 were dehydrated using hot air at 71, 76.7 and 82°C, and microwave energy at 2.45 GHz and different power levels. Quality of the dried foam was evaluated by rehydrating it and determining the color by use of a Hunter-lab color and color difference meter.

INTRODUCTION

Foam-mat drying is a process in which a concetrated product in the liquid or semiliquid state is whipped to form a stable foam, after which the product is dehydrated by exposing thin layers of it to hot air. Foam-mat drying was first developed by Morgan et al. (1961), and since then numerous further investigations of the process and applications have followed (Anonymous 1962; Ginnette et al. 1963; Hart et al. 1963; Bissett et al. 1963; Berry et al. 1965; Beck 1968; Berry et al. 1972). Foam-mat dehydration is a viable method for producing dehydrated products, especially for heat-sensitive foods. The main advantages of the foam-mat drying technique when compared with techniques such as spray or drum drying include lower drying temperatures, shorter time and more rapid reconstitution. All those advantages can be attributed to the bubble structure of the product resulting from the foaming. The resulting increased surface area exposed to the drying air flow accelerates the moisture removal process. On the other hand, as mentioned previously, the product is dried in thin layers usually less than 3.17 mm (1/8 inch) and most frequently is also cratered (Morgan et al. 1961; Berry et al. 1972). The limitation in the thickness of the layers is due to the poor heat transfer within the foamed material. This limitation can be made less critical if the heat is generated within the product itself. Such a possibility is offered by microwave energy.

Microwaves are electromagnetic waves of the frequencies in the range between 100 MHz and 300 GHz and corresponding wavelengths between 3 m and 1 mm. From this broad frequency range, two frequencies are available for industrial heating purposes (two of the ISM frequencies assigned for industrial, scientific and medical use), namely 915 MHz and 2,450 MHz.

The heating of a product exposed to microwave energy occurs as a result of the rotational motion of polar molecules. As the electric field changes, the molecules behave like microscopic magnets and attempt to align themselves with the field. Because of the intermolecular interaction within any substance, there are forces restricting their movement, so that the microwave energy through friction is converted into heat. This mechanism of heat generation by microwave energy results in two very important features, namely, that the heat is generated volumetrically (within the product) and that it is generated instantaneously as the microwave energy penetrates the product. More information on the material parameters' effect on the heat generation and temperature distribution within various food products can be found elsewhere (Bengtsson and Ohlsson 1974). Those unique characteristics of the heat generation by microwave energy have been successfully employed in the processing of various food products, and offer some important inherent advantages when applied to foam-mat dehydration. In foam-mat drying, the poor thermal conductivity of the product is not a limiting factor when the heat is generated by the microwave energy.

This paper presents preliminary results of the comparative experiments of hot-air drying and microwave-power dehydration of tomato paste.

MATERIALS AND METHODS

Foam Preparation

All the tests were carried out for tomato paste (5-1/2-oz cans, manufactured by Hunt) which was found to contain 27% solids.

As a stabilizer, Myverol 18-100 (Kodak serial #2056) was used. Solutions of the tomato paste and stabilizer of a concentration of 1% were prepared in two stages. In the first stage, a small amount of the tomato paste was heated to 69°C and 10% stabilizer stock solution was prepared. In the second stage, the 1% solution was prepared from the tomato paste and the 10% stock solution. In both stages, the solutions were agitated mechanically to ensure uniform dispersion.

The solution of the stabilizer and tomato paste was then whipped in a blender (GE model MF 62AA) at the maximum speed for a specified period of time in order to obtain the foam of required density and stability. The foam density was determined using a method described by Labelle (1966). A 40-ml graduated cylinder was used and special care was taken to avoid formation of air voids while filling the cylinder. The foam stability was evaluated on the basis of the volume change in time (Noyes 1969). For a volume of 50 ml, left for 1 h at 20°C, no change in the volume was observed, which was accepted as an indication of a sufficient desired foam stability. On the basis of the foam density and stability tests, it was decided that the whipping time should be 4.5 min and the density of the foam was then 0.38 ± 0.02 g/cm^3.

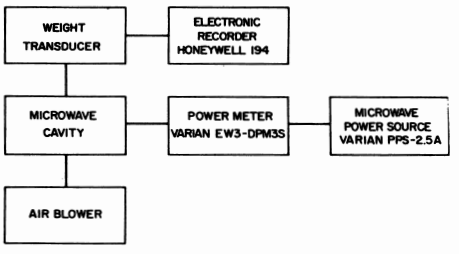

Figure 1. Block diagram of the experimental setup.

Layers of the foam were placed on plates 26.5 cm in diameter. The plates were formed of a Mylar rim supporting a fiberglass teflon-coated mesh. The following thicknesses of the foam were tested: 3.17 mm (1/8 inch), 6.35 mm (1/4 inch) and 12.7 mm (1/2 inch).

Hot-Air Dehydration

A model 150 Fitz-mill fluid bed dryer was used for hot-air dehydration tests. Three samples of each thickness (nine samples together) were dehydrated at temperatures of 71°C (160°F), 76.6°C (170°F) and 82°C (180°F) with air of RH less than 10% flowing at the rate of 0.16 m^3/sec (348 cfm). The air temperature remained constant with ±2°C during each drying cycle.

Microwave-Power Dehydration

An experimental arrangement for dehydration tests with microwave power is shown schematically in Figure 1 and an external view is pictured in Figure 2.

The microwave power source operated at a frequency of 2,450 MHz with an output power level adjustable continuously in the range 0-2.5 KW. The power delivered to and reflected from a drying chamber (microwave cavity) was monitored by the power meter. Monitoring of both the forward and reflected powers allowed for calculation of the power dissipated in the test product and the cavity walls (the power dissipated in the walls usually can be neglected). For the drying chamber, a circular cylindrical multimode cavity was used. The cavity was 39.2 cm in diameter and 46.5 cm in height. Both the bottom and the removable lid were perforated with holes 5 mm in diameter spaced 8 mm apart in order to allow for the air flow. As the cavity was designed for a different application (Rzepecka et al. 1975), it did not ensure uniform electric field distribution. On the other hand, a conventional microwave oven could not be used since an adjustable power source and a power monitor were required.

To the top lid outside of the cavity, a weighing system was attached. It consisted of a Statham UC3 universal transducing cell, a UL4 load cell accessory and an HP 6216A power supply. The output from the transducing cell was connected to the electronic recorder. This weighing system permitted recording of the test sample weight changes during the drying process with an accuracy estimated as ±2 g. The test samples were suspended on a teflon rod attached to the weight transducer and they were positioned 18.5 cm from the top of the chamber.

Air at room temperature (20°C) and relative humidity of 59% was forced through the cavity at a rate of 0.187 m^3/sec (400 cfm) by a blower placed under the cavity.

The temperature of the test samples was indicated by a Thermindex temperature-indicating device, type 1, series A and B. These temperature indicators are labels with dots of heat-sensitive materials that change their color when a certain specified temperature is attained. Three such labels were attached to each test sample and the highest temperature was noted.

The drying tests were performed for five forward power settings between 150 W and 350 W with a 50 W increment. As mentioned previously, the reflected power was also monitored. It was found that when the sample reached a moisture content of about 20%, the reflected

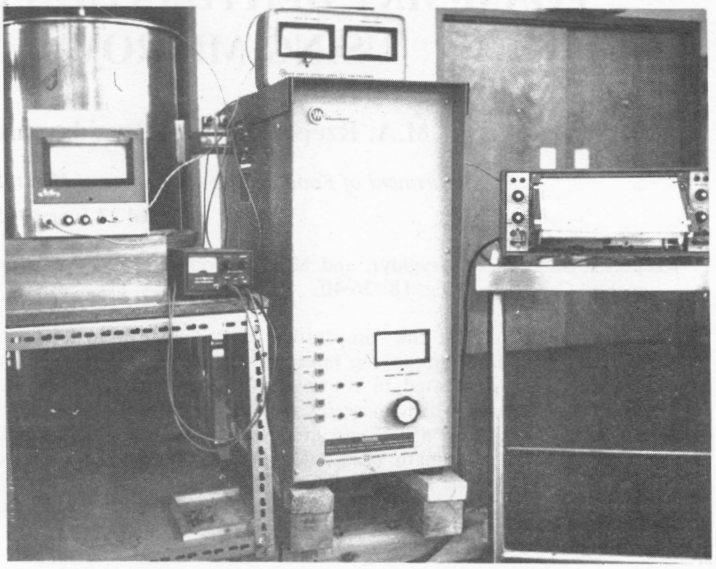

Figure 2. External view of the experimental setup.

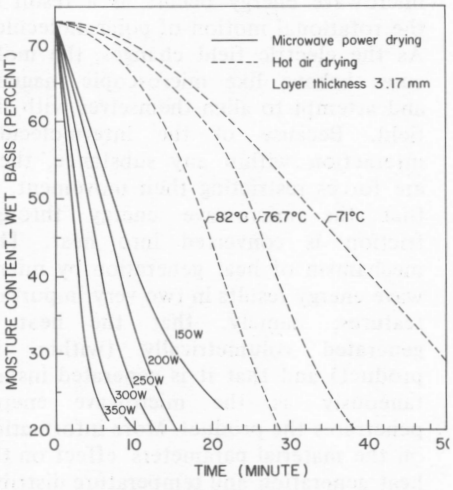

Figure 3. Moisture content of tomato paste vs. drying time.

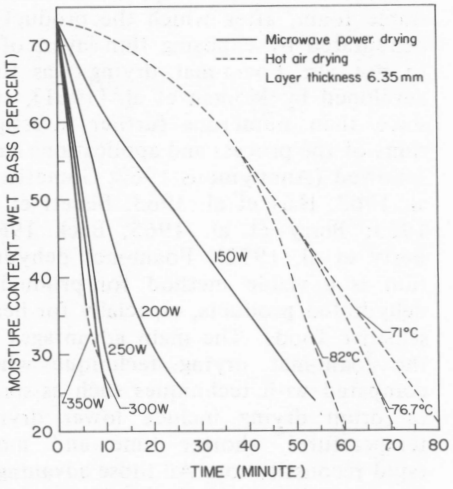

Figure 4. Moisture content of tomato paste vs. drying time.

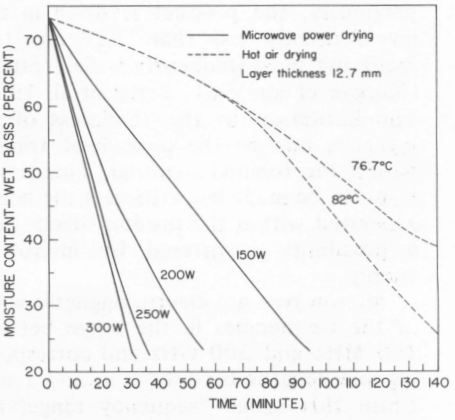

Figure 5. Moisture content of tomato paste vs. drying time.

TABLE I COMPARISON OF THE TOTAL MICROWAVE ENERGY DISSIPATED IN THE SAMPLE FOR DIFFERENT FOAM THICKNESSES AND FORWARD POWER LEVELS

Foam thickness (mm)	Power forward (W)	Time† (min)	Energy/water removed‡ W min/ml
3.17	150	22	50
	200	15	50
	250	12	30
	300	9.0	40
	350	6.5	40
6.35	150	52	110
	200	26	50
	250	12	30
	300	10	30
	350	8.5§	30
12.7	150	94	70
	200	54	60
	250	36	50
	300	30	40
	350	18§	50

† Time of drying until about 20% of the moisture content of the sample was obtained.
‡ The reflected power was monitored, and the power dissipated was calculated as the difference: P forward – P reflected; the energy then was calculated as the sum of the products (approximating the integral) of the power dissipated multiplied by the time for each period when the power dissipated remained constant.
§ Final moisture content about 30%.

TABLE II MAXIMUM TEMPERATURE OF THE SAMPLES DRIED WITH MICROWAVE POWER

Foam thickness (mm)	Power forward (W)	Temperature (°C)
3.17	150	54.5 – 60
	200	60.0 – 65.5
	250	60.0 – 65.5
	300	65.5 – 71
	350	71 – 77
6.35	150	65.5 – 71
	200	71 – 77
	250	77 – 82
	300	93 – 99
	350	82 – 88
12.7	150	71 – 72
	200	77 – 82
	250	88 – 93
	300	93 – 99
	350	77 – 82

power was nearly equal to the forward power. This fact limited the test capabilities of the described experimental arrangement to a moisture content of about 20%. As this resulted from the design of the microwave cavity, the results reported here have to be limited to this range, but this does not limit the applicability of the microwave power to this moisture content region only.

Color Determination

All the dehydrated samples were rehydrated to the original moisture content (73%) and subjected to color analysis and comparison with the raw tomato paste. For color evaluation, a Hunter-lab color and color difference meter, model 25, with a standard plate D25-1333, was used (with an L value of 93.8, aL of −1.1, bL of 2.3 and CTC value of −4.7). The color measurements were averaged over three samples for each rehydrated sample and over seven replicates for the raw tomato paste which was used as a reference standard for comparison.

Tomato paste color is the most important factor in quality evaluation. Other tests would involve a taste panel evaluation and were not undertaken at this stage.

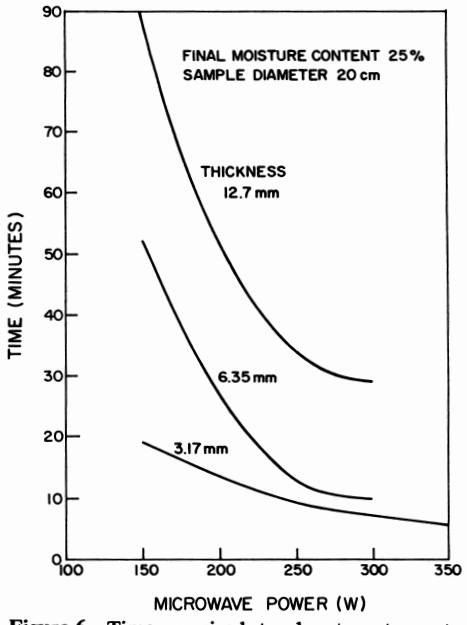

Figure 6. Time required to dry tomato paste samples as a function of the level of the microwave power (forward).

RESULTS AND DISCUSSION

Dehydration Rate

The drying curves showing the change of moisture content of the tomato foam vs. time are shown in Figures 3-5 for three foam thicknesses for the two methods of dehydration, namely, by hot air at specified temperatures and by microwave energy at specified power levels. The comparison is done only for the moisture content changes down to 20%, due to the previously mentioned difficulties with the microwave cavity used. At lower moisture content, problems were experienced with efficient coupling of the microwave power to the cavity. Another limitation in the dehydration, using the described experimental setup with the microwave energy, resulted from the use of unconditioned air for moisture removal. The air used was of room temperature, about 20°C, and relative humidity 59%.

It can be seen (Figures 3-5) that the moisture content change as a function of time is entirely different for the two methods of dehydration. It is worth mentioning that in both techniques the experimental arrangements provided sufficiently large air flow, so that the effect of air velocity on the drying rate was eliminated. The water removal from the free surfaces was not, therefore, a limiting factor in the experiments. The moisture removal rate was much faster at any of the examined levels of microwave power, for each of the thicknesses, than for the hot-air dehydration. Especially for the samples of thicknesses 6.35 mm and 12.7 mm the difference was significant. For both of those thicknesses the initial

TABLE III COLOR EVALUATION FOR SAMPLES DEHYDRATED BY HOT AIR

Foam thickness (mm)	Temp. (°C)	Color	aL/bL	$\sqrt{aL^2 + bL^2}$	ΔE
3.17	71	L 36.3 aL 23.1 bL 17.3	1.33	28.86	64.16
	76.7	L 35.3 aL 25.6 bL 18.2	1.40	31.41	66.24
	82	L 31.3 aL 24.4 bL 16.3	149	39.76	68.93
6.35	71	L 34.0 aL 24.8 bL 18.0	1.37	30.64	67.0
	76.7	L 31.7 aL 25.6 bL 16.8	1.52	30.62	69.13
	82	L 27.3 aL 20.5 bL 13.9	1.47	24.76	70.87
12.7	71	L 30.5 aL 23.4 bL 16.0	1.46	28.34	69.24
	76.7	L 27.1 aL 19.0 bL 13.5	1.40	23.30	70.55
	82	L 21.6 aL 12.0 bL 9.7	1.23	15.43	73.77
Untreated sample	20	L 27.3 aL 23.3 bL 1.90	1.90	26.28	71.52

L is a measure of lightness-darkness. The higher the L value, the lighter the sample.

aL indicates the redness-greenness of the sample. The higher the aL reading (i.e. the more positive it is), the redder the sample. The smaller the value (i.e. the more negative it is), the greener the sample.

bL indicates the yellowness-blueness of the sample. The larger or more positive the bL value is, the more yellow. The smaller or more negative the value, the more blue the sample.

ΔE is a value indicating total color difference between the Hunter-lab standard plate and the sample.

$$\Delta E = \sqrt{\Delta L^2 + \Delta aL^2 + \Delta bL^2}$$

where $\Delta L = 93.8 - L$ value of sample

$\Delta aL = -1.1 - aL$ value of sample

$\Delta bL = 2.3 - bL$ value of sample

aL/bL is the hue value; $\sqrt{aL^2 + bL^2}$ is the saturation value.

moisture removal by the hot-air method was very slow, due to the slow heat transfer from the material surface toward the centre.

Figure 6 shows the time required to dry the samples to a moisture content of 25% on a wet basis vs. the level of microwave power going toward the cavity (forward). It should be noted that not all the forward power is dissipated in the test sample. The increase of the power forward caused a decrease in the drying time, as expected, although the rate of change is not linear. It is interesting to note that an increase of the forward power over 300 W for the examined sample (26 cm diam) for the thicknesses of 6.35 ands 12.7 mm results in a very small decrease in drying time. As mentioned previously, more significant even that the power forward is the power dissipated in the dried sample. The power dissipated in the sample is equal to the difference between the power forward and the power reflected, both of them being monitored during the experiment. The total energy dissipated in the sample during the dehydration can then be calculated and is shown in Table I. The energy shown in the table was calculated with the accuracy of 15%.

Table II shows the maximum temperatures of the samples. The temperature was measured at three points for each sample.

Color Evaluation

Hot-air drying

Color evaluation for hot-air-dried samples is summarized in Table III. The lightness values (L) decreased with increased temperatures and foam thicknesses. Such results indicated that exposures at higher temperatures or for longer time periods (as would be necessary with thicker foams) caused toasting of the product. The aL and bL values did not seem to follow an appreciable trend at the 3.17-mm and 6.35-mm foam thicknesses. At these levels and temperatures, the redness and yellowness of the samples was unaffected. However, at the 12.7-mm foam thickness, a correlation of increased temperature with lower aL and bL values was observed. Such prolonged exposures to high temperatures began to adversely affect the quality of the color.

The saturation and hue values followed trends similar to the aL and bL values, and the interpretations would at this time seem to be the same. However, the total color difference (ΔE) results indicate a definite linear pattern. As the temperature and foam thickness increased, the ΔE value also increased, showing that such variables if uncontrolled may adversely affect total color. In comparison to the ΔE value for the untreated sample, however, the results are not significantly different, indicating that in general the total color, under treatments utilized, was not affected.

Samples dehydrated by microwave power

Color evaluation results for samples dehydrated by microwave power are summarized in Table IV. The L values show no appreciable trend, thus indicating no lightness-darkness effects. However, as with the hot-air drying, maximum power settings at the maximum foam thickness gave slightly lower L readings. The aL and bL values, unlike the values for the hot-air tests, showed no trend. Also, no trend in the hue, saturation and total color difference was observed. All the color parameters of the microwave-dehydrated samples were very close to the parameters of the untreated samples, so no adverse effects on the color quality were observed.

CONCLUSIONS

The preliminary results of the comparative studies of foam-mat dehydration of tomato paste by a conventional hot-air method and a microwave energy method demonstrated some important advantages of the microwave method. The drying time was substantially decreased when

TABLE IV COLOR EVALUATION FOR SAMPLES DEHYDRATED BY MICROWAVE POWER

Foam thickness (mm)	Power forward (W)	Color	aL/bL	$\sqrt{aL^2 + bL^2}$	ΔE
3.17	150	L 30.8 aL 22.0 bL 14.5	1.51	26.34	68.20
	200	L 30.6 aL 25.3 bL 15.7	1.61	29.77	69.79
	250	L 30.4 aL 23.4 bL 15.8	1.48	28.33	69.29
	300	L 30.2 aL 26.9 bL 16.4	1.64	31.49	70.37
	350	L 28.0 aL 24.1 bL 15.9	1.16	28.87	71.76
6.35	150	L 31.1 aL 22.4 bL 15.5	1.44	27.23	68.24
	200	L 30.3 aL 21.4 bL 15.2	1.40	26.24	68.59
	250	L 28.9 aL 24.6 bL 14.8	1.66	28.70	70.91
	300	L 29.4 aL 20.2 bL 14.1	1.43	24.63	68.84
	350	L 29.3 aL 16.9 bL 12.6	1.34	21.08	67.75
12.7	150	L 27.9 aL 21.7 bL 13.8	1.57	25.71	70.67
	200	L 28.3 aL 22.3 bL 13.6	1.63	26.11	70.46
	250	L 28.3 aL 21.4 bL 14.0	1.52	25.57	70.23
	300	L 29.0 aL 20.4 bL 13.5	1.51	24.46	69.18
	350	L 26.4 aL 21.2 bL 13.2	1.60	24.92	71.82

microwave energy was used, especially for the mats of greater thicknesses. The color of the product was not adversely affected even when the temperature of the product was higher than the temperature used in hot-air dehydration.

Further studies involving the effects of the physical parameters of the foam on the dehydration rates and final product color are being carried out. A new microwave power applicator is also being designed, which should improve the microwave power coupling efficiency in order to dry the samples to the required moisture content of 4-5%.

ACKNOWLEDGMENTS

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