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Microwave Drying of Mango Slices at Controlled Temperatures

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ABSTRACT: The main objective of this study was to investigate microwave drying of mango slices at a constant temperature using a laboratory microwave applicator. The product temperature was maintained at 60, 70 and 80°C. The effects of the three product temperatures for sample thickness of 2 mm on drying characteristics of moisture content, drying time and moisture ratio were studied. Furthermore, convective air drying at three temperatures (60, 70 and 80°C) and for sample thickness of 2 mm was performed to compare the drying characteristics of microwave with conventional method. Results indicated that the temperature profile of microwave heating consisted of two periods; namely, the period of temperature increases at constant power and the period of constant temperature by controlling the power. Microwave drying of mango slices at constant temperatures follows typical drying curves. Increasing the surface temperatures faster drying times for the samples. Microwave drying resulted in 70-75 % decrease in the drying time as compared to convective air drying.

KEYWORDS: Microwave; mango slices; temperature control; drying curve.

1 INTRODUCTION

Microwave drying is an alternative drying method which offers a considerable reduction of drying time. In microwave drying the product is exposed to high frequency electromagnetic waves. These high-frequency waves selectively excite the polar molecules (dipoles) and ions, causing them to align themselves with the rapidly changing direction of the electrical field. In this process of orientation, sufficient heat is generated throughout the material to evaporate moisture from within the mass. This creates a total pressure gradient, which promotes rapid movement of liquid water and water vapor towards the surface of the material, and hence very rapid drying takes place without the need to overheat the atmosphere [1].Moreover, microwave application has been reported to improve product properties resulting in a better aroma and faster and better rehydration with considerable saving in energy [2].

Drying temperature and microwave power are the two most important factors in microwave drying of agricultural products. These two factors significantly influence the drying parameters such as drying time, drying curve, drying speed, drying efficiency and the final product quality [3]. In a typical microwave drying application, a fixed microwave power level is applied throughout the entire drying process, but a temperature control is usually not included. A microwave drying process can be divided into three periods according to temperature variations: a warming-up period in which sample temperature increases with little moisture removal; a constant temperature period in which most of the drying takes place; and a heating-up period when the drying rate decreases and sample temperature increases rapidly [4]. While the drying effects in the first and second periods are acceptable, product charring often occurs in the last period when the temperature reaches an undesirable high value. To achieve an ideal drying effect over the entire drying process, sample temperature must be controlled and microwave power must be adjusted, especially in the last drying stages. Unfortunately, such study is seldom reported in the literature [3], although it had been recommended by some researchers [5], [6]. A microwave drying of fruit at a constant temperature usually follows a typical drying curve [7]. A number of studies have been conducted to improve microwave drying [8],[9],[6], yet no study was reported on attempts to control the drying temperature during the microwave drying process of mango slices. Therefore, the objectives of this study were: (1) to investigate the possibility of microwave drying of mango slices at controlled temperatures of 60, 70 and 80°C and (2) to investigate the microwave drying curve variations with respect to drying temperatures (3) to compare microwave drying with convective air drying.

2 MATERIALS AND METHODS

2.1 MICROWAVE SYSTEM

The drying experiments were performed using a laboratory microwave system, which was designed at the Section of Agricultural Engineering, Department of Crop Sciences, University of Goettingen, Germany. The generator and the magnetron were developed by Muegge (Reichelsheim, Germany). The system operates at a frequency of 2.45GHz.

As shown in Fig.1, the microwave applicator consists of microwaves source, magnetron with an adapted power capacity range from 120 to 1200W. The magnetron was modified to produce a continuous output power. Standard waveguide (R-26) coupled vertically into the resonant chamber and the electromagnetic waves are reflected into this chamber. To prevent a damage of the magnetron caused by reflected energy, a circulator was incorporated into the waveguide in order to absorb the reflected power. Furthermore, the waveguide was equipped with a directional coupler to detect the amount of the reflected energy and to measure the input power. The volume of its cavity was about (34.5cm *22.5cm*34 cm). Inside the cavity there is a special porous Teflon plate, which suspended in a scale. The Teflon plate coupled with a rotary device with different rotation speeds and with a sensitive balance to measure the mass online. An infrared pyrometer (Heimann KT 19.82) was installed on the top of the cavity to measure the surface temperature of the product during microwave application. The microwave system is integrated with a special software program to read continuously: product surface temperature (maximum, average and minimum); power (output and reflected); sample mass and duration. All data were measured and recorded each 10 seconds online. To remove the moisture, a fan was installed on the back of the cavity and the fan air speed was measured using a hot wire anemometer. The speed of the fan was kept constant throughout the experiment.

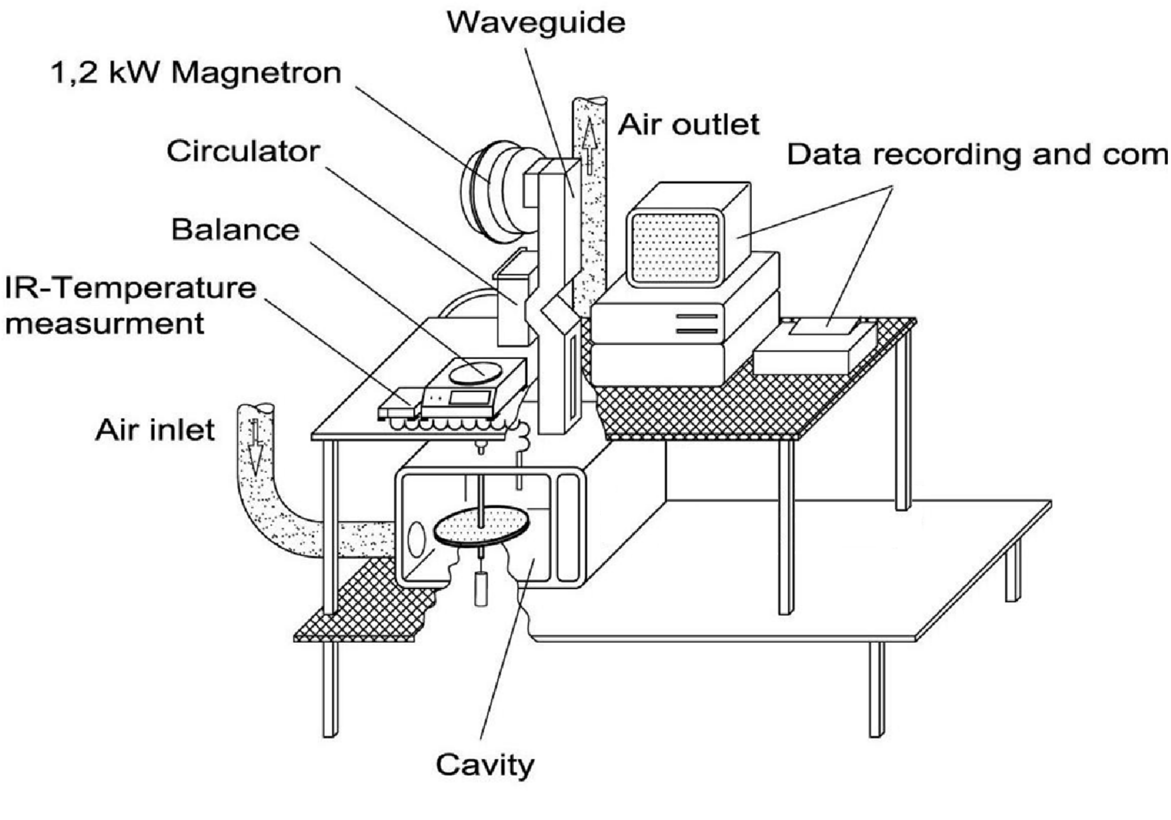

Fig.1. Schematic diagram of the laboratory microwave system

2.2 SAMPLE PREPARATION

Fresh mangoes, var. *Kent*, were purchased from a local supermarket in Goettingen, Germany and stored in a refrigerator at 4 ±0.5°C. Prior to drying, samples were taken out of the refrigerator and left for 5 days for post-harvest ripening at 25±2 ºC and 50% relative humidity in a climatic chamber [10]. The fruits were then washed with tap water, manually peeled using a stainless steel knife, and sliced using an electric food-slicer (Krups variotronic, Germany) to a thickness of 2 mm. To ensure homogenous drying, the shape of slices was standardized by using a template of 45 x 20 mm.

2.3 MICROWAVE DRYING PROCEDURE

In this study microwave heating was applied to investigate the drying characteristics of mango slices at three controlled product surface temperatures (60, 70 and 80°C) and for product thickness of 2mm. The starting applied microwave power was kept constant at 700W (after some pretrial experiments) for the selected three temperatures to obtain the desired target temperature, and then the temperature kept constant by adjusting the microwave output power manually until the moisture content reached around 8.0±0.5% (w.b.). The average initial moisture content of the mango fruit was 86.7±0.2 %(w.b.), as determined using a precision air-oven method, at a temperature of 135°C for 2 hours until constant weight was reached, according to the standard method of AOAC [11] and moisture content on wet basis(w.b.) was calculated by the following equation:

$$\mathrm{MC_{wb}} = \frac{\mathrm{W_w}}{\left(\mathrm{W_w} + \mathrm{W_d}\right)} \text{ x100\%} \qquad (1)$$

Where:

MC_{wb} = moisture content, percent, wet basis

W_w = weight of water, g

W_d = weight of dry matter, g

Moisture content on wet basis was converted to moisture content on dry basis by the following equation:

$$MC_{db} = \frac{MC_{wb}}{\left(100 - MC_{wb}\right)} \qquad (2)$$

Where: MC_{db} = moisture content, decimal, dry basis

About 90±0.2 g of mango slices were weighed using a sensitive balance (Sartorius, LA 6200, Goettingen, Germany) and placed on the Teflon plate as a single layer and then transferred into the microwave cavity. The plate with samples was suspended under the sensitive balance of ±0.01g accuracy, which was located on the top of the microwave applicator for mass measurement and the plate was also coupled with the rotating device. The speed of the plate rotation was set at 19 rpm. The fan was turned on and set at a constant airflow velocity of 0.5m/s. The samples were dried until the moisture content reached about 8.0±0.5 %(w.b.). All experiments were performed in duplicate. In addition, the mango slices were dried in a convective air oven (Heraeus, UT6120, Germany) with an airflow rate of 0.5 m/s and at three temperatures (60, 70 and 80°C). Changes in mass during hot air drying were recorded offline using a sensitive balance with ±0.01g precision at 10 min intervals. The drying process was stopped when the moisture content decreased to about 8.0±0.5% (w.b.). All the drying experiments were replicated twice at each drying temperature and the average values were used for drying characteristics of mango slices.

2.4 MICROWAVE DRYING CURVES

The moisture ratio and drying rate of mango slices during drying experiments were calculated using the following equations:

$$\text{MR} = \frac{M - Me}{Mo - Me} \qquad (3)$$

Where: MR is the dimensionless moisture ratio; M, M_0 and M_e are the moisture content at any time, initial moisture content and equilibrium moisture content, respectively. The equilibrium moisture content (M_e) was assumed to be zero for microwave drying [12], [2], [13]. Therefore, MR can be simplified as:

$$MR = \frac{M}{Mo} \tag{4}$$

$$\text{Drying rate} = \frac{M_{t+dt} - M_t}{dt} \tag{5}$$

Where, M_t , and M_{t+dt} are the moisture content at t and moisture content at t+dt (kg water/kg dry matter), respectively, t is drying time (s).

2.5 Statistical Analysis

Statistical analysis was conducted using Minitab version 16. Significant differences (p<0.05) between means were evaluated by one-way ANOVA and Tukey's test.

3 Results And Discussion

3.1 Microwave Heating Of Mango Slices

Fig.2. shows the microwave heating process. The average initial temperature of product was 20°C and it was increased to the desired temperatures 60, 70 and 80°C. From the figure it is clear that, the temperature profile of microwave heating consisted of two periods: the period of temperature increases at constant power 700W and the period of constant temperature by controlling the power. The temperatures for the three set of experiments (60, 70 and 80°C) were recorded and compared in the figure 2. The drying temperature was almost constant throughout the experiment. The microwave power was adjusted in such a way; by holding and turning the microwave power valve manually, anti-clockwise when the temperature increased beyond the set point and clockwise when the temperature of the product decreased below the set point. However, the microwave power never exceeded 700W. So the temperatures of mango slices were varied slightly with respect to the set temperature. Similar observations were reported by Li et al. [3] for microwave apple drying at constant temperatures (55, 65 and 75°C) and Nair et al. [14] for microwave corn drying at constant temperatures (30, 40 and 50°C).

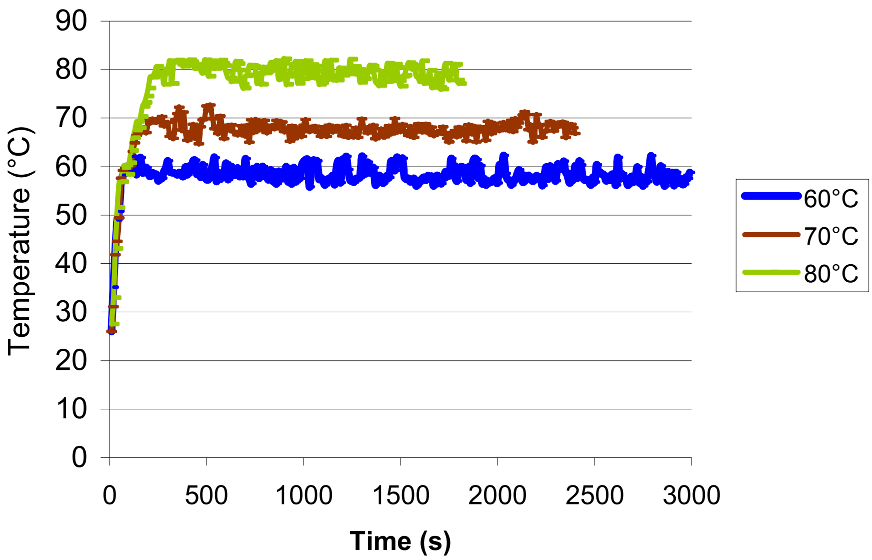

Fig.2. Temperatures of mango slices at controlled temperature microwave drying

3.1.1 TEMERATURE CONTROL DURING MICROWAVE DRYING

The capability of the microwave system to keep the controlled temperature during the drying process at the desired values; namely 60, 70 and 80°C was shown in the fig. 2. The highest temperature used was 80C since above this temperature serious charring could occur, making the final product quality totally unacceptable [15]. The average temperatures recorded on mango slices was closed to the corresponding set point values within difference values of 1.08, 2.22 and 2.89°Cfor 60, 70 and 80°C, respectively, as shown in Table 1. Temperature fluctuations became larger while the process goes on, because of increase of the power density (7.8W/g at time 0) in the last phase of the drying period due to samples' mass reduction.

The maximum temperature overshoot recorded during the drying at 80°C was 6.0°C, could lead to product charring and the final quality considered unacceptable. Hence, there is a need to control the temperature in the drying process to improve drying effects in terms of temperature control, time and energy efficiency and product quality. Similar results were reported by Li et al. [3].

Table 1 also showed that the temperature oscillations increased as temperature increases. Such behavior could be a consequence of the reduction in dielectric loss factor with temperature increase which requires higher time to keep surface temperature fixed. As a consequence the instantaneous overall temperature level of the mango slices increased. The corresponding average powers for the selected temperatures (60, 70 and 80°C) were 473, 608 and 698W, respectively.

Table1. Set temperatures, averages, maximum, temperature oscillations and average output power during microwave drying of mango slices at constant temperature

T(°C)	T_{avg} (°C)	T_{max}(°C)	(T-T_{avg})	T_{max}-T_{avg}	average Power(W)
60	58.02	64.4	1.08	6.38	473
70	67.78	74	2.22	7.22	608
80	77.11	86	2.89	8.89	698

3.2 MICROWAVE DRYING CHARACTERISTICS OF MANGO SLICES

The microwave drying characteristics of mango slices are shown in Fig. 3. The initial moisture content of mango slices before drying was about 86.7±0.2 %, w.b. (mean ± std. deviation). As expected, the drying temperature (microwave power) had a significant effect on drying characteristics of the mango slices. The moisture content decreased continuously with time and an increase in temperature (microwave power) resulted in reduced drying time. The longest and shortest drying time were recorded at 60°C and 80°C, respectively. The drying times required to reduce the moisture content of mango slices from 86.7±0.2 % (w.b.) to the final 8.0±0.5 %(w.b.) were 1800, 2400 and 3000s at 80°C, 70°C and 60°C, respectively, as shown in Fig. 5. Mango slices drying were faster at higher temperatures, with reduction of drying time. Microwave absorption provokes internal water heating and evaporation, greatly increasing the internal pressure and concentration gradient and thus the effective water diffusion [16]. Drying temperature (microwave power) had a significant effect on drying time, increasing temperature from 60 to 80°C resulted in 20% reduction in drying time.

Mango slices during microwave (MW) processing showed typical drying rate, obtained taking the time derivative of corresponding curves represented in Fig.3. Their characteristics showed the typical trend for fruit drying. The moisture content of the material was very high during the initial phase of the drying which resulted in a higher absorption of microwave power and higher drying rates due to the higher moisture diffusion. As the drying progressed, the loss of moisture in the product caused a decrease in the absorption of microwave power and resulted in a drop in the drying rate. Higher drying rates were obtained at higher product temperature. Thus, the microwave output power (drying temperature) had a crucial effect on the drying rate.

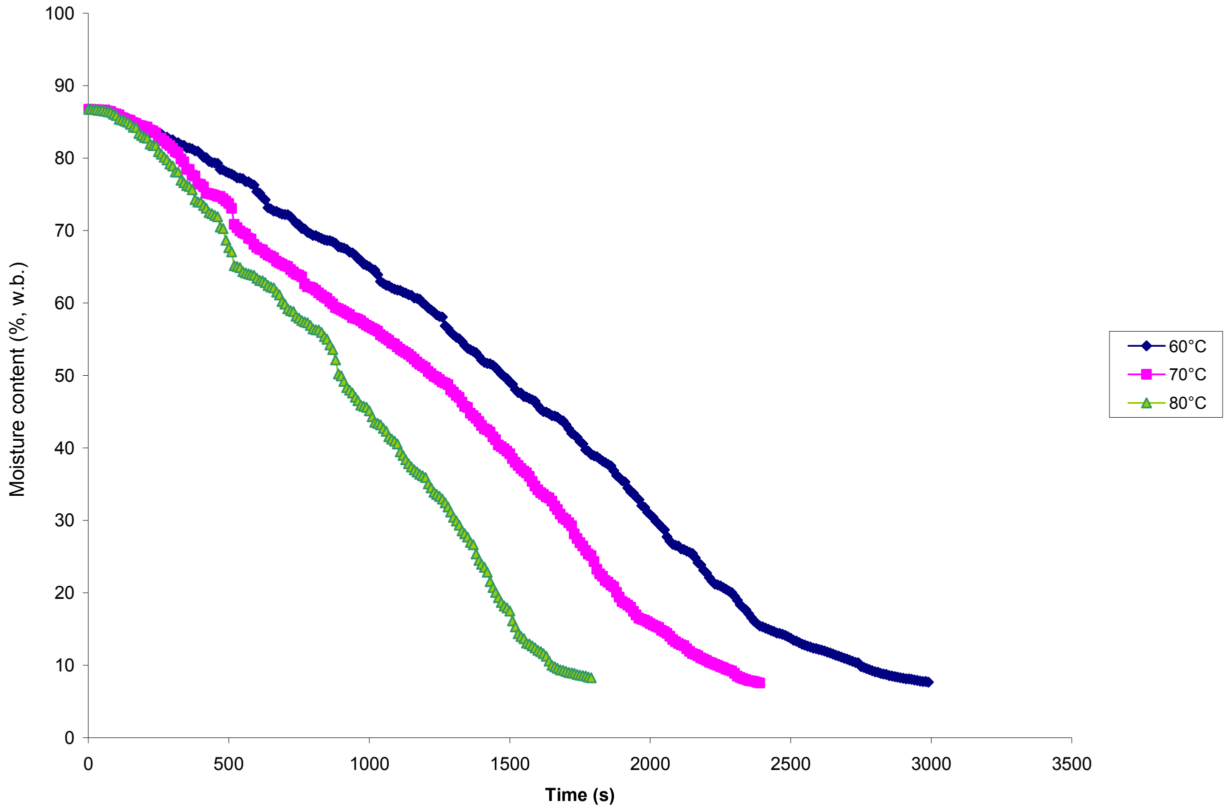

Fig.3. Moisture content % (w.b.) versus drying time at constant temperatures microwave drying

Fig.4. shows moisture ratio of the mango slices plotted versus drying time. From the figure it is clear that moisture ratio decreased considerably with increasing drying time. The time required to reduce the moisture ratio to any given level was dependent on the drying temperature, being highest at 60°C and lowest at 80°C. It was observed that the main factor influencing drying kinetics was the drying temperature (microwave power). Thus, a higher drying temperature produced a higher drying rate and consequently the moisture content decreased faster.

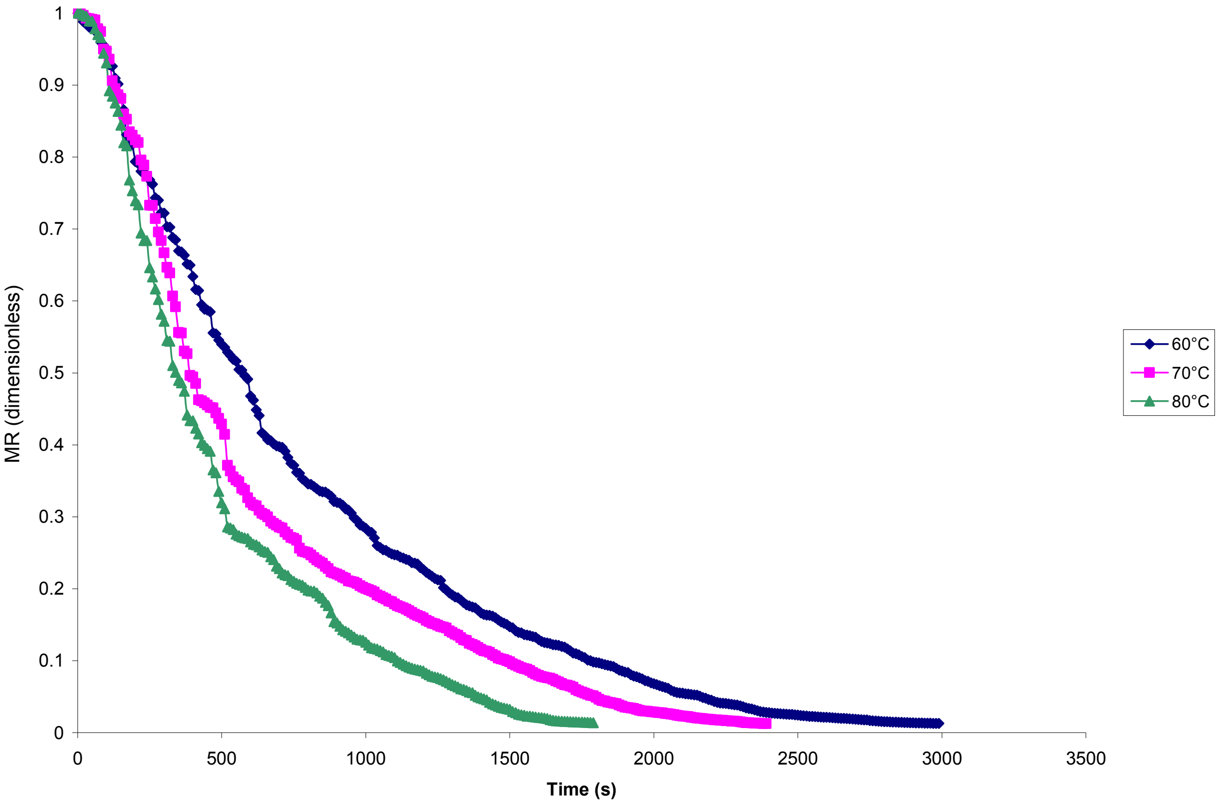

Fig. 4. Drying curves of moisture ratio versus drying time for the three temperatures

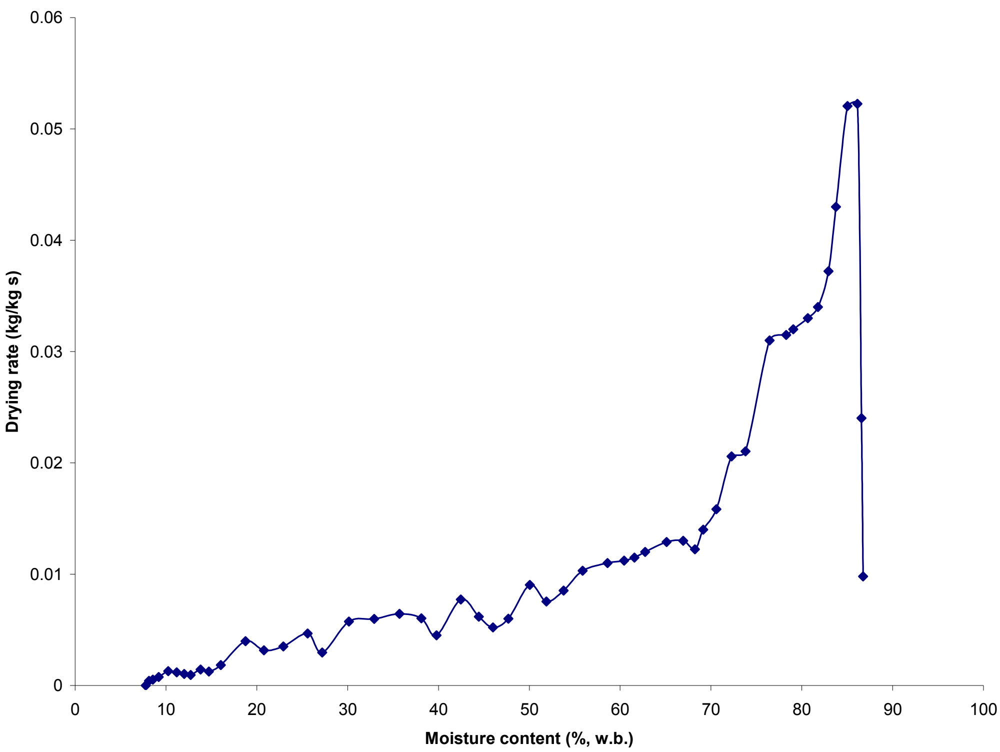

Fig.5. Drying rate curve of mango slices dried by microwave at constant temperature of 60°C

The drying rate was calculated as the quantity of moisture removed per unit time per unit dry matter. The drying rate plotted against moisture content was shown in Fig. 5. It can be seen that the thin layer microwave drying process of mango slices exhibited only two drying periods: heating up and falling rate periods. Similar results reported for banana [2] and kiwi fruit [17].

3.3 Comparison Of Microwave And Convective Air Drying Of Mango Slices

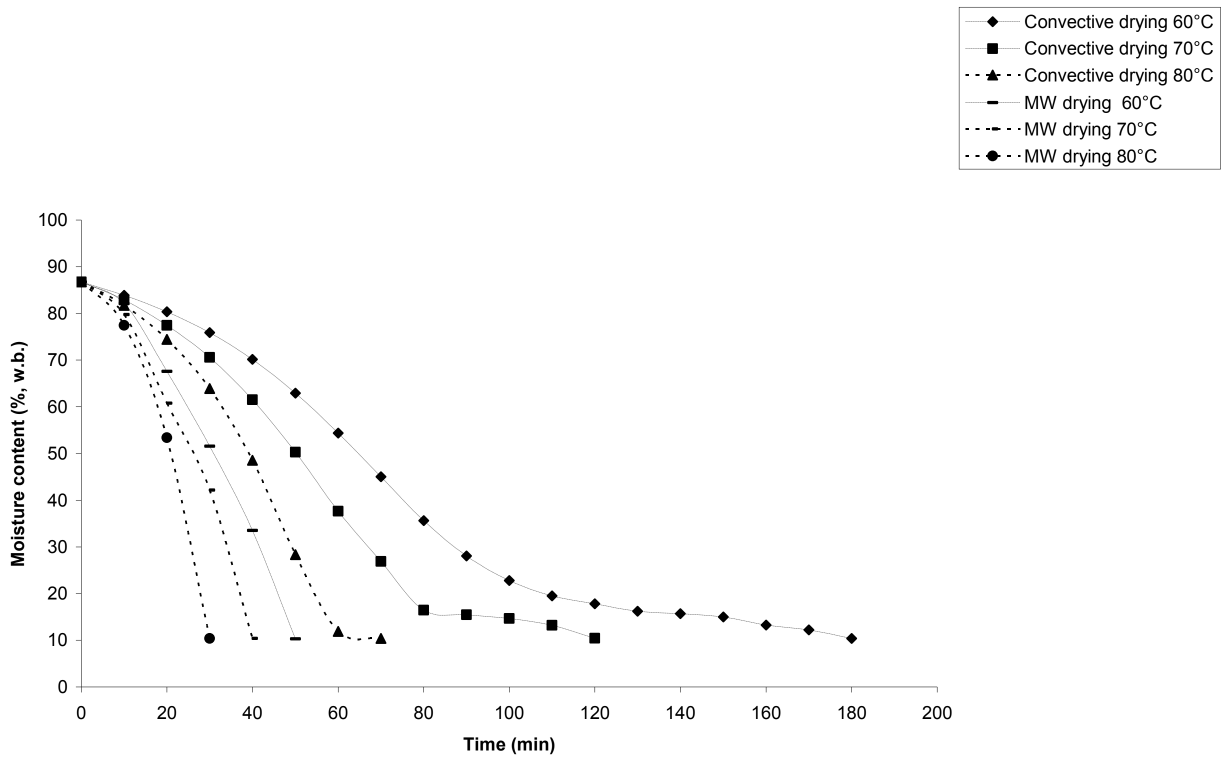

Fig.6. Moisture content % (w.b.) versus drying time for microwave (MW) and convective air drying of mango slices

Mango slices were dried with two different drying methods: microwave (MW) and hot air drying to reduce the moisture content of mango slices from 87.6% to about 8.0+0.5%. The influence of microwave power and drying air temperature on the moisture content versus drying time are shown in Fig. 6. The drying times to reach the final moisture content for microwave drying were 30, 40 and 50 min at 473, 608 and 698W (corresponding to 60,70 and 80°C), respectively. While that for hot air drying were 70, 120 and 180 min at 60, 70 and 80°C, respectively. The time required for microwave drying of mango slices was much shorter than that for hot air drying. Statistical analysis showed a significance difference ($p<0.05$) between drying times of microwave and hot air drying. This phenomenon indicated that the mass transfer of drying sample was rapid during microwave heating because microwave penetrated directly into the sample. The heat was generated inside the sample and provided fast and uniform heating throughout the entire product, thus creating a large vapor pressure differential between the centre and surface of product allowing rapid transport and evaporation of water. An increased in microwave power significantly shortened the drying time. Similar results were reported by Sumnu et al. [16], Ozkan et al. [18], and Wang et al. [19] on the study of microwave drying of carrot, spinach and apple pomace, respectively. In hot air drying, increasing of drying air temperature also shortened the drying time significantly. However, microwave drying resulted in 70-75% reduction in drying time as compared to hot air drying. Similar results were reported by Maskan [2] with 64.3% reduction in drying time for microwave drying of banana, Giri and Prasad [20] with 70-90% reduction in drying time for microwave-vacuum drying of mushrooms and Therdthai and Zhou [21] with 85-90% reduction in drying time for microwave vacuum drying of mint leaves

4 Conclusions

Microwave drying of mango slices at controlled temperatures resulted in consistent temperatures. The microwave drying technique can be successfully used to dry mango slices with maximum gain in time. Drying time is decreased significantly with increase in drying temperature (microwave output power). After a short heating period, the process attained very high drying rates followed by the falling rate period during which maximum drying took place. Drying time of the samples was significantly reduced from 50 min to 30 min as the power input increased from 473 to 698W.furthermore, as compared to hot air drying, microwave drying reduced drying time by 70-75%. An automatic temperature control system is recommended for microwave drying at a constant temperature. The results can be used to determine microwave power levels in microwave drying process of mango slices with temperature control.

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