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Experimental Assessment of Energy and Mass Transfer in Microwave Drying of Fig Fruit

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ABSTRACT

Energy and mass transfer investigations in thermal processing of fruits serve as a breakthrough in the design and scale up of drying systems. Diffusivity characteristics and specific energy consumption for drying of fig fruit in a laboratory scale microwave dryer were assessed. Several intervals for microwave power intensity including 0.5, 1, 1.5, 2, and 2.5 W g^{-1}, and 6 levels of power on-off stated as pulsing ratios of 1.5, 2, 2.5, 3, 3.5, and 4 were employed. The results showed that the drying rate decreased with the pulsing ratio and increased with microwave power intensity. Effective moisture diffusivity as an indicator of mass transfer was obtained to be higher at elevated microwave power intensities. Also, increased pulsing ratios had a reducing effect on moisture diffusivity. Using 2^{nd} law of Fick, moisture diffusivity was calculated to be varying from 5.93E-10 to 1.42E-08 m^2 s^{-1} depending on the experimental conditions. Furthermore, the activation energy of fig fruit was obtained to be in the range of 60.094 to 92.189 kJ mol^{-1}. Specific energy consumption variations showed a positive correlation with pulsing ratio and drying time. However, due to the dependence of energy consumption on MW power intensity, a multiple regression analysis with R^2 of 0.968 was developed.

Keywords: Activation energy, Diffusivity, Pulsed drying, Specific energy consumption.

INTRODUCTION

Fig (*Ficus carica* L.) is a important crop in Iran with a yearly production of 76,414 tones and an economic value of about 4,5619,000 US$ ranking forth in the world (FAO, 2010). Fresh fig is very sensitive to microbial spoilage and even in cold storage conditions it must be preserved, canned or dried in order to have a long shelf time (Doymaz, 2005). In general, postharvest losses are estimated to exceed 30% and it could be reduced to a great extent by adequate drying of products (Imre, 2006). Drying is one of the important preservation methods employed for storage of figs since the dawn of civilization (Jayaraman and Das Gupta, 2006). Fig fruit can be dried either by traditional methods (sun drying) or in conventional hot-air dryers (Babalis *et al*., 2006). In spite of the advantage of direct sun drying, several difficulties such as rain and cloudiness, contamination, lack of control and microbiological spoilage due to long exposure are known (Jayaraman and Das Gupta, 2006). On the other hand, using hot-air drying, fig is exposed to elevated drying temperatures, which leads to an increase in shrinkage and toughness. Also conventional hot-air drying causes serious damage to flavor, color, and nutrient content of fruits (Altan and Maskan, 2005). These drawbacks, plus with long drying time and low energy efficiency, have motivated researchers to think out alternative drying methods. Alternative drying techniques are developed to meet one or more of the following criteria: enhanced product quality, higher capacity, reduced drying time, easier control, and reduced energy consumption (Kudra and Mujumdar, 2006).

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MicroWave (MW) drying is a technology that is being used increasingly in the food industry due to its considerable advantages in heat transfer compared to conventional drying (Knoerzer *et al*., 2006). MW drying is rapid, much uniform, and energy efficient in comparison with conventional hot air drying (Zheng *et al*., 2004; Wang *et al*., 2007). Nevertheless, some quality loss is always accompanied when foods are dried completely using MW due to raised product temperature during drying. Some strategies employed to improve dried product quality include combination of MW and conventional hot air drying, pulsed drying, and MW-vacuum drying. Pulsed drying can control product temperature and enhance product quality especially for temperature sensitive products such as fruits (Gunasekaran, 1999). Furthermore, pulsed application of MW energy is found to be more efficient than continuous mode (Jayaraman and Das Gupta, 2006).

MW drying is basically a sophisticated process of complex phenomena. Therefore, effective models are necessary for process design, optimization, energy integration, and control (Marinos-Kouris and Maroulis, 2006). Significant mass and energy transfer features to be highlighted in modeling, designing, and optimizing of drying process are effective moisture diffusivity, activation energy, and specific energy consumption. Moisture diffusivity represents the effect of all input parameters on the mass transfer in drying process (Hashemi *et al*., 2009). However, diffusion phenomena are extremely complex, especially for MW drying. Minimum energy requirement for starting the drying process is known as activation energy. Specific energy consumption expresses the total energy consumption divided by the amount of water removed during drying process (Sharma and Prasad, 2006).

Although a considerable amount of data has been reported in the literature regarding the transport properties in the drying such as green pepper (Darvishi *et al*., 2013), persimmon slices (Doymaz, 2012), drumstick leaves (Premi *et al*., 2012), coriander leaves (Sarimeseli, 2011), seedless grape (Chayjan *et al*., 2011), carrot pomace (Kumar *et al*., 2011), fig fruit (Xanthopoulos *et al*., 2010; Doymaz, 2005), pistachio nut (Rafiee *et al*., 2009) and tomato pomace (Al-Harahsheh *et al*., 2009), there is no information concerning MW for determining transport phenomena in drying of fig fruit. Moreover, the specific energy consumption change for MW drying of fig fruit has not been reported.

The main purpose of this study was to investigate the effects of the MW power intensity and pulsing ratio on mass and energy transfer criteria including drying rate, drying time, moisture diffusivity, activation energy, and specific energy consumption during drying of fig fruit in a laboratory scale MW dryer. Online measurement of mass and temperature within the oven was accomplished, which is vital for precise assessment of mass and energy balance in the drying process.

MATERIALS AND METHODS

Experimental Procedure

Figs (Rashe variety) were obtained locally from Sardasht, Iran, and stored in a refrigerator at 4±1°C. Just before drying, samples were taken out from the refrigerator to ambient temperature (20°C). They were visually inspected and the defected samples were eliminated. The three principal dimensions of figs were measured by a micrometer with an accuracy of 0.01 mm and then geometric mean diameter and sphericity of products were calculated using the relationships given by Mohsenin (1986). The mean values of geometric mean diameter and sphericity were found to be 31.57±1.16 mm and 93.11±2.34%, respectively. Samples were then immediately weighed and placed in a 32 cm diameter tray and submitted to MW radiation. AOAC standard (AOAC, 1990) was used to determine initial moisture content of fresh fruits during the tests. No pre-treatment was applied to the fresh product.

A laboratory scale MW oven (Panasonic 686S model, Matsushita Electric Ind. Co. Ltd., Japan) was used. The tray and fan were readjusted to be controlled individually. The fan of the oven ran continuously at 0.5 m s^{-1} air velocity throughout the experiments for vapor removal. Sample tray was installed upon a motor driver located on top of the load cell (ZEMIC model, L6D–C3–5 kg) beneath the oven housing. Motor driver rotates sample tray to evenly distribute the MW power. Simultaneously, the sample mass was recorded and displayed in a digital display integrated with the load cell. A thermometer (PT100 sensor with accuracy of 0.1°C) warped with aluminum foil and insulated with paint was inserted in the geometric center of a singular sample for temperature measurements. This sample was placed at the center of the tray (Figure 1). During MW drying, weight and temperature of the samples were measured at regular intervals (10 seconds). Subsequently, measured data were transferred to the PC to be recorded with a "National Instruments LabView" program (Run-Time Engine 6.0 version). Additionally, the control panel of oven was modified to allow the power-on and power-off durations to be controlled with a microcontroller, which could continuously and automatically adjust the on-off MW power known as pulsing ratio. For the reason of energy assessment, the whole consumed electrical energy was measured with an energy meter during the experiments as illustrated in Figure 1. The energy meter measured instant power and then calculated the total energy by integrating the amount of instant power values over the drying period.

Theoretical Principle

Factors investigated in the present research were: MW power intensity (0.5, 1, 1.5, 2, and 2.5 W g^{-1}), and pulsing ratio (1.5, 2, 2.5, 3, 3.5, and 4) selected according to data

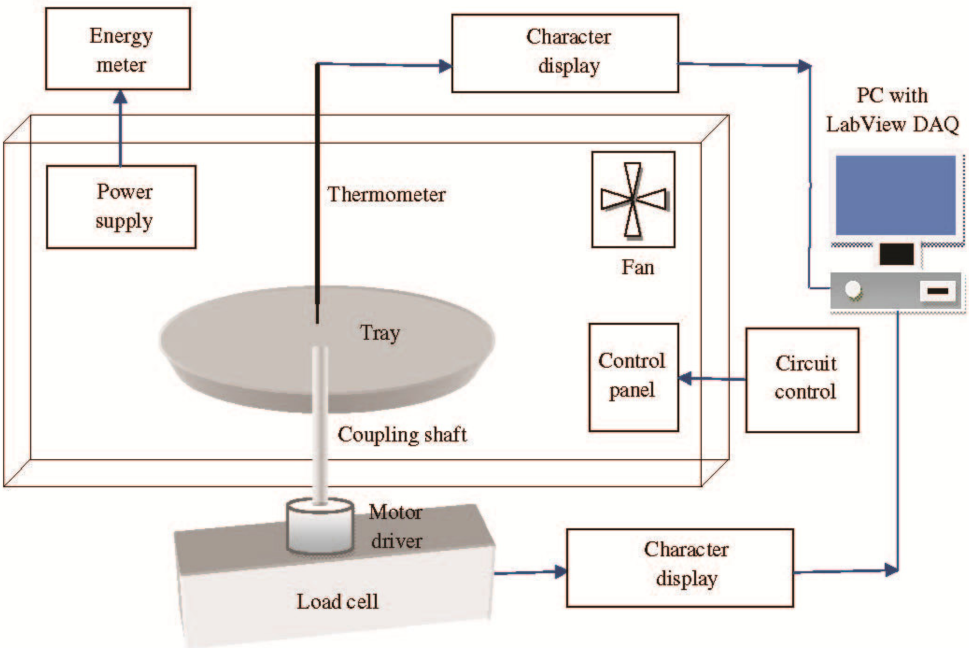

Figure 1. Schematic illustration of the MW drying system.

extracted from pretests i.e. factors to guarantee a safe and suitable temperature of drying of fig fruits. The Pulsing Ratio (PR), defined in Equation (1), is presented in Table 1 (Gunasekaran, 1999):

$$PR = \frac{\text{On time cycle power} + \text{Off time cycle power}}{\text{On time cycle power}} \quad (1)$$

The Drying Rate (DR) is expressed as the amount of the evaporated moisture over time. The drying rates of fig fruit (in kg water kg^{-1} dry matter s^{-1}) were calculated using Equation (2) (Al-Harahsheh *et al*., 2009):

$$DR = \frac{M_{t+\Delta t} - M_t}{\Delta t} \quad (2)$$

Where, M_t and $M_{t+\Delta t}$ are moisture content at *"t"* and *"t+Δt"* (kg of water kg^{-1} of dry matter), respectively, while *"t"* represents the drying time (s).

Assuming that moisture movement is one-dimensional and that the moisture diffusivity is constant, Fick's second low can be expressed as:

$$\frac{\partial M}{\partial t} = D_e \frac{\partial^2 M}{\partial t^2} \quad (3)$$

General solution of Fick's second law in spherical coordinate is stated by Crank (1975), in which negligible equilibrium moisture content, spherical samples, no shrinkage during drying, constant moisture diffusivity, uniform initial moisture distribution and negligible external mass transfer resistance was assumed:

$$MR = \frac{M}{M_o} = \frac{6}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{n^2} \exp\left(\frac{-n^2 \pi^2 D_e t}{r^2}\right) \quad (4)$$

Where, M and M_o stand for the present moisture content and initial moisture content, respectively, r is the radius in meter, t is the drying time in second and D_e is the moisture diffusivity in m^2 s^{-1}. For long drying times, Equation (4) can be simplified by taking the first term of series solution:

$$MR = \frac{6}{\pi^2} \exp\left(\frac{-\pi^2 D_e t}{r^2}\right) \quad (5)$$

Equation (5) could be further simplified to a straight-line equation as:

$$Ln\,(MR) = Ln\left(\frac{6}{\pi^2}\right) - \left(\frac{\pi^2 D_e t}{r^2}\right) \quad (6)$$

The effective moisture diffusivity is generally calculated using the method of slope. It is typically determined by plotting experimental drying data in terms of *Ln(MR)* versus time (Doymaz, 2012). From Equation (6), a plot of *Ln(MR)* versus time gives a straight line with a slope of K_o:

$$K_o = \frac{\pi^2 D_e}{r^2} \quad (7)$$

From Equation (7), by using a linear regression procedure, the effective diffusivity of fig fruit and related coefficient of determination (R^2) were obtained. Additionally, the effect of temperature on diffusivity can be described by an Arrhenius equation (Marinos-Kouris and Maroulis, 2006; Doymaz, 2012):

$$D_e = D_o \exp\left(-\frac{E_a}{R\,T}\right) \quad (8)$$

Where, D_o is the pre-exponential factor of the Arrhenius equation (m^2 s^{-1}), E_a is the activation energy for the moisture diffusion (kJ mol^{-1}), R is the ideal gas constant (0.0083143 kJ mol^{-1} °K), and T (°K) is the average internal temperature of samples generated through the dipole changing mechanism of the MW radiation (Jayaraman and Das Gupta, 2006). Unlike the conventional hot air drying systems, internal heat generation in MW drying results in a relative uniform and steady heat transfer mode. Equation (8) could be simplified to a straight-line equation as:

$$Ln\,(D_e) = Ln\,(D_o) - \frac{E_a}{RT} \quad (9)$$

Table 1. Defined pulsing ratios as a variable factor in the experiments.

Power-on time (s)	30			60		
Power-off time (s)	15	45	75	60	120	180
Pulsing ratio	1.5	2.5	3.5	2	3	4

From Equation (8), plot of $Ln(D_e)$ against $1/T$ gives a straight slope of K_1:

$$K_1 = \frac{E_a}{R} \tag{10}$$

From Equation (10), using a linear regression analysis to fit the equation to the experimental data, the activation energy of fig fruit and related coefficient of determination (R^2) were calculated.

The consumption of energy was related to the quantity of lost water (Wang *et al*., 2007) and expressed as specific energy consumption. The specific energy consumption was estimated considering the total energy supplied to dry figs from initial moisture content varying between 3.168 and 4.302 kg water kg^{-1} dry matter to a desired moisture level. Specific energy consumption (H), in MJ kg^{-1} was defined as follows (Sharma and Prasad, 2006):

$$H = \frac{\text{Total energy supplied in drying process}}{\text{Amount of water removed during drying}} = \frac{h_1 + h_2 + h_3}{W_r} \tag{11}$$

Where, h_1 is the energy requirement of the magnetron in MJ; h_2 is the energy requirement for rotating samples' tray in MJ; h_3 is the energy requirement of the fan in MJ, and W_r is the amount of water removed during the drying process in kg.

RESULTS AND DISCUSSION

Drying Rate and Drying Time

The drying rate of samples as a function of drying time is presented in Figure 2 for 0.5, 1.5 and 2.5 W g^{-1} levels of MW power intensities. The drying rate increased dramatically at the first stage of drying, during which samples were warmed-up and internal sample temperature was enhanced. For the second stage of drying, moisture content diminished with increase in drying time and then drying rate inclined towards constant rate. A major part of MW energy is here dedicated for moisture removal of samples hence a significant section of the drying takes place. Subsequently, drying rate decreased at the end of drying because of decreasing in moisture content of the products. According to Doymaz (2005), drying was continued until the samples reached the desired moisture content (25±0.5%, wet basis).

Figure 2 indicates that the drying rate decreases with increase in pulsing ratio, regardless of MW power intensities, and it can also be noticed that the rise in pulsing ratio increased the duration time of drying process. Furthermore, the drying rate of fig fruit rose with increasing MW power intensity at a constant pulsing ratio. This observation is in agreement with previous literature studies on MW drying of spinach (Karaaslan and Tunçer, 2008), tomato pomace (Al-Harahsheh *et al*., 2009) and coriander leaves (Sarimeseli, 2011). This indicates that moisture transfer within the sample is more rapid during higher MW power intensities because more heat is generated within the sample creating greater vapor pressure difference between the center and the surface of the product due to characteristic MW volumetric heating (Wang and Sheng, 2006).

Effective Diffusivity and Activation Energy

The effective moisture diffusivities of fig fruit under various MW power intensities and pulsing ratios are presented in Table 2. The values ranged from 1.42E-08 at 2.5 W g^{-1} MW power intensity to 5.93E-10 m^2 s^{-1} at 0.5 W g^{-1} MW power intensity, when pulsing ratios were 1.5 and 4, respectively. These diffusivity values were higher than those for hot-air drying which were estimated in the range of 3.97E-10 to 7.8E-10 m^2 s^{-1} for peeled and unpeeled figs (Xanthopoulos *et al*., 2010) and for sun drying of fig which was reported to be about 2.47E-10 m^2 s^{-1} (Doymaz, 2005). Calculated values of diffusivity lay within the general range of 10^{-11} to 10^{-8} m^2 s^{-1} for 82% of food

Table 2. The Effective moisture diffusivity and related slope of K_o and coefficient of determination.

MPI [a] (W g^{-1})	K_o [b] (s^{-1})	D_e [c] ($m^2 s^{-1}$)	R^2 [d]	K_o (s^{-1})	D_e ($m^2 s^{-1}$)	R^2	K (s^{-1})	D_e ($m^2 s^{-1}$)	R^2
	PR [e]: 1.5			PR: 2			PR: 2.5		
0.5	-8.13E-05	2.05E-09	0.967	-5.49E-05	1.39E-09	0.9673	-4.59E-05	1.16E-09	0.996
1	-1.84E-04	4.65E-09	0.9497	-1.21E-04	3.06E-09	0.9579	-9.42E-05	2.38E-09	0.9672
1.5	-3.04E-04	7.68E-09	0.9484	-2.10E-04	5.30E-09	0.9455	-1.62E-04	4.08E-09	0.9579
2	-4.08E-04	1.03E-08	0.9607	-3.30E-04	8.33E-09	0.9611	-2.45E-04	6.19E-09	0.953
2.5	-5.62E-04	1.42E-08	0.9639	-4.21E-04	1.06E-08	0.9707	-3.12E-04	7.88E-09	0.9771
	PR: 3						PR: 4		
0.5	-4.42E-05	1.16E-09	0.9796	-3.12E-05	7.88E-10	0.9841	-2.35E-05	5.93E-10	0.9885
1	-7.07E-05	1.79E-09	0.9726	-6.22E-05	1.57E-09	0.9821	-4.63E-05	1.17E-09	0.9741
1.5	-1.32E-04	3.33E-09	0.9599	-1.10E-04	2.79E-09	0.969	-8.22E-05	2.08E-09	0.9533
2	-2.01E-04	5.09E-09	0.9729	-1.51E-04	3.82E-09	0.976	-1.34E-04	3.37E-09	0.9656
2.5	-2.62E-04	6.63E-09	0.9777	-1.99E-04	5.02E-09	0.9816	-1.75E-04	4.42E-09	0.9745

[a] MW Power Intensity; [b] Slope; [c] Effective moisture diffusivity, [d] Coefficient of determination; [e] Pulsing Ratio;

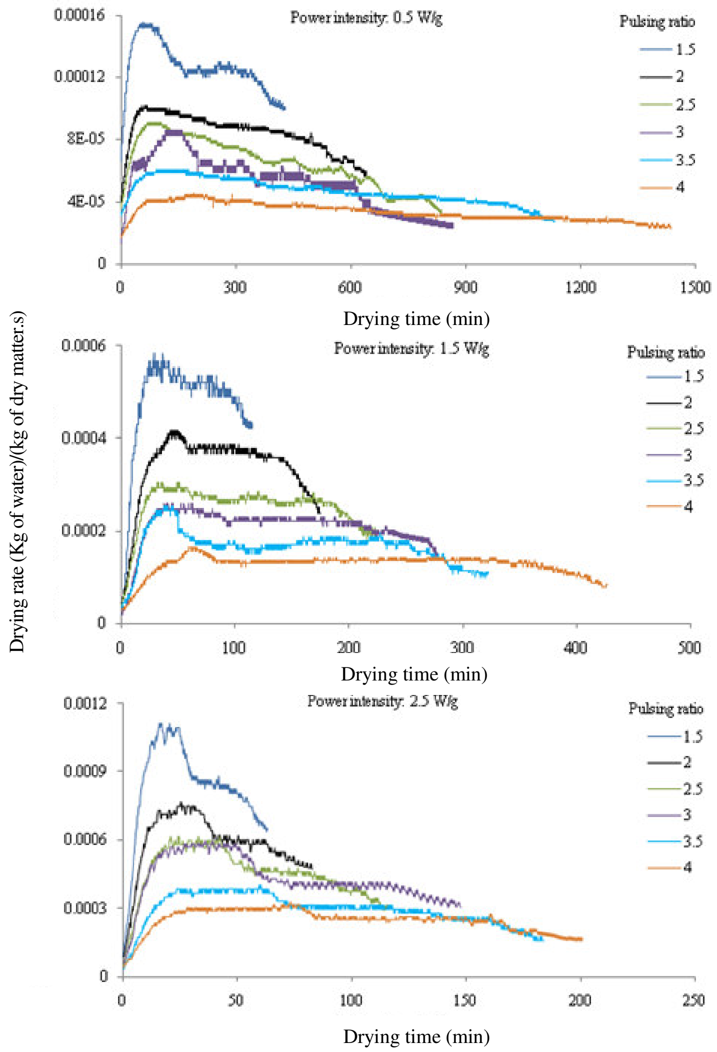

Figure 2. Variation of drying rate as a function of drying time at selected pulsing ratio and 0.5, 1.5 and 2.5 W g^{-1} power intensities.

materials (Marinos-Kouris and Maroulis, 2006).

As expected, the diffusivity values were higher with the increase of MW power intensity due to the rise in temperature and, consequently, water vapor pressure. They were low when the pulsing ratio increased (Figure 3). This maybe because of sample cooling as a result of power-off-times at high pulsing ratios. Similar observations were recorded by Sarimeseli (2011) for coriander leaves. Equations (12) to (17) represent the effect of temperature on effective diffusivity for all 6 pulsing ratio levels.

$$D_e = 7001.64 \exp(-9944.7/T), \quad PR = 1.5 \tag{12}$$

$$D_e = 202602.25 \exp(-11088/T), \quad PR = 2 \tag{13}$$

$$D_e = 33223.08 \exp(-10416/T), \quad PR = 2.5 \tag{14}$$

$$D_e = 145.46 \exp(-8479.9/T), \quad PR = 3 \tag{15}$$

$$D_e = 3.55 \exp(-7227.8/T), \quad PR = 3.5 \tag{16}$$

$$D_e = 32.26 \exp(-8028.8/T), \quad PR = 4 \tag{17}$$

The calculated values of activation energy for different levels of pulsing ratio are presented in Figure 4. It is evident from Figure 4 that as MW pulsing ratio was increased from 2 to 3.5, the activation energy diminished from 92.189 to 60.094 kJ mol^{-1}; however, the aforementioned trend

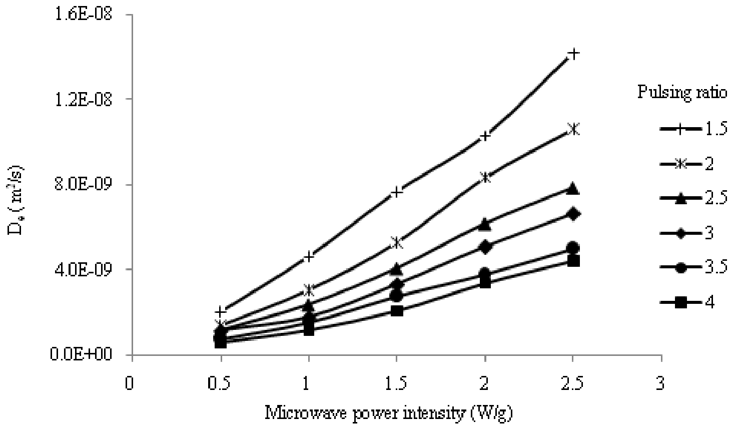

Figure 3. Variation of effective moisture diffusivity as a function of MW power intensity at selected levels of pulsing ratio.

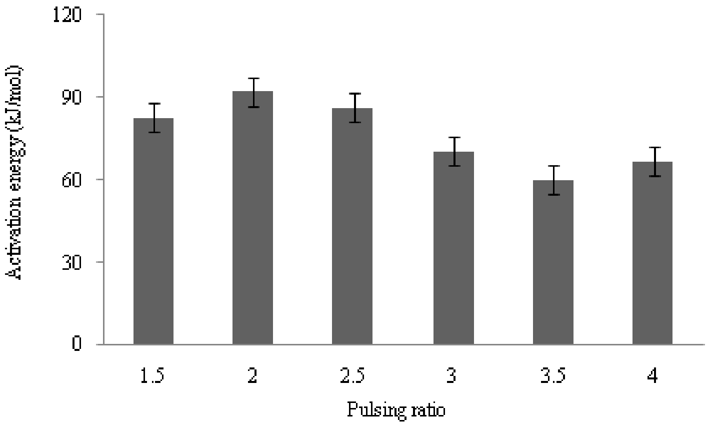

Figure 4. Activation energy under different levels of pulsing ratio.

was not observed at higher levels. This was because of the reduction in the sample temperature with increase in pulsing ratio. Our results indicated that the obtained values for activation energy were in the suitable range due to the fact that E_a values for food and agricultural products were commonly located in the range of 12.7-110 kJ mol^{-1} (Chayjan *et al*., 2011).

Specific Energy Consumption

Specific energy consumption is a function of MW power intensity and pulsing ratio (Figure 5). Results illustrated that the specific energy consumption decreased with MW power intensity at all pulsing ratio levels, which comply with the results of the study on garlic cloves (Sharma and Prasad, 2006). The highest specific energy consumption, i.e. 29.58 MJ kg^{-1}, was recorded at 0.5 W g^{-1} MW power intensity, when the pulsing ratio was 4. This condition corresponds to the maximum drying time (1,436 minutes). Considering the continued operation of fan during the experiments, which consumed 60W power, the maximized energy consumption would be justified. On the other hand, the minimum specific energy consumption was 9.72 MJ kg^{-1} obtained at 2.5 W g^{-1} MW power intensity and 1.5 pulsing ratio which corresponds to the minimum drying time of 63 minutes (Table 3).

Using multiple regression analysis, a polynomial relationship was established between MW Power Intensity (MPI), Pulsing Ratio (PR) and specific energy consumption (H) (Figure 5). The regression equation and the associated coefficient of determination (R^2) are presented in Equation

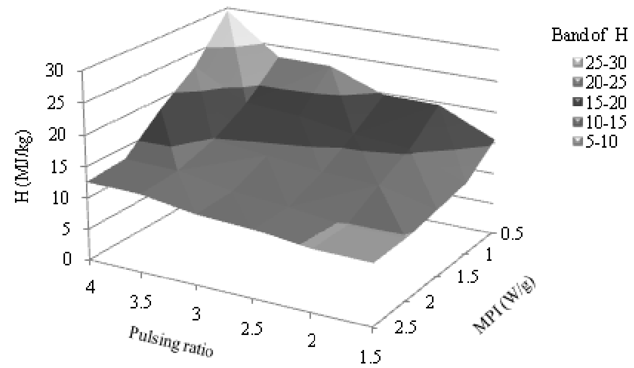

Figure 5. Interaction of MW power intensity and pulsing ratio on specific energy consumption

Table 3. Specific energy consumption and drying time under various MW power intensities and pulsing ratios.[a]

MPI [a] (W g^{-1})	H [b] (MJ kg^{-1})	t [c] (Min)	H (MJ kg^{-1})	t (Min)	H (MJ kg^{-1})	t (min)
	PR [d]: 1.5		PR: 2		PR: 2.5	
0.5	15.562	429	19.596	640	19.759	836
1	11.716	196	15.378	285	16.137	378
1.5	10.732	115	12.782	175	13.056	225
2	9.808	82	9.847	113	10.833	147
2.5	9.718	63	9.790	82	10.795	117
	PR: 3		PR: 3.5		PR: 4	
0.5	23.012	866	23.080	1130	29.580	1436
1	17.493	500	18.069	564	22.650	751
1.5	13.961	278	14.822	322	18.350	426
2	11.428	176	12.995	237	13.127	258
2.5	11.207	148	12.447	184	12.625	201

[a] MW Power Intensity; [b] Specific energy consumption, [c] Drying time; [d] Pulsing Ratio.

(18). Using this equation, energy consumption can be predicted at any given MW power intensity and pulsing ratio.

$$H=15.652-8.585(MPI)+3.159(PR)+2.736(MPI)^2+0.426(PR)^2-1.82(MPI)(PR),\ R^2= 0.968 \quad (18)$$

CONCLUSIONS

Online measurement of mass and energy transfer criteria for microwave drying of fig fruit was achieved based on which the following conclusions are deduced:

Increasing MW power intensity from 0.5 to 2.5 W g^{-1} increased the drying rate and, consequently, decreased drying time by 570%. Specific energy consumption decreased by 96% with the MW power intensity changing from 0.5 to 2.5 W g^{-1} whereas, at the corresponding range of pulsing ratio from 1.5 to 4, specific energy consumption increased by 67%.

The diffusivity values increased with MW power intensity due to the increase in temperature and decreased with pulsing ratio. The temperature dependence of the effective diffusivity was also described by the Arrhenius type relationship.

In the pulsing ratio range of 2 to 3.5, the lowest value of activation energy (60.094 kJ mol^{-1}) was calculated at 3.5 pulsing ratio while maximum amount of activation energy (92.189 kJ mol^{-1}) was obtained at pulsing ratio of 2.

Nomenclature

D_e: Effective moisture diffusivity ($m^2\ s^{-1}$)
D_o: Pre-exponential factor of the Arrhenius equation ($m^2\ s^{-1}$)
DR: Drying Rate (kg water kg^{-1} dry matter s^{-1})
E_a: Activation energy (kJ mol^{-1})
H: Specific energy consumption (MJ kg^{-1})
h_1: Energy requirement of the magnetron (MJ)
h_2: Energy requirement for rotating samples' tray (MJ)
h_3: Energy requirement of the fan (MJ)
K_o: K_1 slope of line
M: Moisture content at any time (kg of water kg^{-1} of dry matter)
M_o: Initial moisture content (kg of water kg^{-1} of dry matter)
M_t: Moisture content at t (kg of water kg^{-1} of dry matter)
$M_{t+\Delta t}$: Moisture content at $t+\Delta t$ (kg of water kg^{-1} of dry matter)
MR: Moisture Ratio (Dimensionless)
MPI: Microwave Power Intensity
MW: MicroWave
PR: Pulsing Ratio
R: Ideal gas constant (0.0083143 kj mol^{-1} °K)
R^2: Coefficient of determination
r: Radius (m)
T: Absolute temperature (°K)
t: Time (s)
W_r: Amount of water removed during the drying process (kg)

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ارزیابی تجربی انتقال جرم و انرژی در خشک کردن مایکروویو میوه انجیر

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چکیده

بررسی انتقال جرم و انرژی در فراوری حرارتی میوه‌ها می‌تواند در طراحی و افزایش مقیاس سیستم‌های خشک کردن بسیار مفید واقع گردد. در این پژوهش با به کارگیری یک دستگاه خشک‌کن آزمایشگاهی مایکروویو ویژگی‌های نفوذ و انرژی مخصوص مصرفی برای میوه انجیر ارزیابی شد. با استفاده از طرح آماری فاکتوریل در قالب طرح کاملاً تصادفی، تأثیر تغییرات دو عامل چگالی توان مایکروویو در پنج سطح ۰/۵ ، ۱ ، ۱/۵ ، ۲ و ۲/۵ وات بر گرم و نسبت پالسی در شش سطح ۱/۵، ۲، ۲/۵، ۳، ۳/۵ و ۴ بر پارامترهای زمان خشک کردن، آهنگ تبخیر، ضریب نفوذ رطوبت، انرژی فعال‌سازی و انرژی مخصوص مصرفی با سه تکرار مورد ارزیابی قرار گرفت. نتایج نشان داد که آهنگ خشک شدن محصول با کاهش نسبت پالسی و نیز با افزایش چگالی توان مایکروویو افزایش پیدا می‌کند. ضریب نفوذ مؤثر به عنوان شاخص خوبی از انتقال جرم با افزایش چگالی توان و کاهش نسبت پالسی افزایش می‌یابد. با استفاده از قانون دوم فیک، مقدار ضریب نفوذ مؤثر انجیر بسته به شرایط آزمایشات در بازهٔ $۱۰^{-۱۰}$ × ۵/۹۳ تا $۱۰^{-۸}$ × ۱/۴۲ متر مربع بر ثانیه بدست آمد. با افزایش نسبت پالسی از ۲ به ۳/۵، مقدار انرژی فعال-سازی از ۶۰/۰۹۴ به ۹۲/۱۸۹ کیلوژول بر مول کاهش یافت. تغییرات انرژی مخصوص مصرفی با نسبت پالسی و زمان خشک کردن همبستگی مثبتی نشان داد. با توجه به وابستگی این پارامتر به چگالی توان مایکروویو آنالیز رگرسیونی چند متغیره با ضریب تبیین ۰/۹۶۸ انجام شد.