Shrimp Drying Characterizes Undergoing Microwave Treatment

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Abstract

In this paper, a laboratory microwave oven was used to dry the shrimp, applying microwave power in the four levels of 200, 300, 400 and 500W. Results indicated that drying took place in the falling rate period. The drying rate increased with drying microwave power, but decreased with moisture content. The effective diffusivity varied from 1.54×10^{-10} to $1.43\times10^{-9}m^2/s$. About 22.54% increase in drying efficiency and about 28.94% (0.937MJ/kg[H_2O]) decrease in specific energy consumption could be obtainable by increasing the microwave power from 200 to 500W.

Keywords: Microwave drying, Shrimp, Specific energy consumption, Effective diffusivity

1. Introduction

Drying is one of the oldest methods of food preservation and it is a complex process and involves simultaneous mass and heat transfer. The temperature, drying time, moisture diffusivity and drying rate are vital parameters in the design of process like for instance drying, storage, aeration and ventilation, etc.

Different conventional thermal treatments are used in the drying of biologic product such as, hot-air drying, vacuum drying, sun-drying and freeze drying result in low drying rates in the falling rate period which leads to undesirable thermal degradation of the finished products (Mousa and Farid, 2002; Vadivambal and Jayas, 2007; Ozbek and Dadali, 2007).

So that compared with these drying techniques; microwave drying offers opportunities as rapid and relatively uniform heating achieved, shorter operating time, high thermal efficiency, space utilization, sanitation, energy saving, precise process control, fast start-up, shut-down conditions and high quality of the finish product (Khraisheh et al., 2004; Sharma and Prasad, 2004; Ozkan et al., 2007; Reyes et al., 2007; Varith et al., 2007).

Dried shrimp is one of the most important exported marine products in many countries such as Thailand, China, Malaysia and United States. Lin et al (1999) have compared microwave vacuum and air and freeze drying on product quality for drying of shrimp. Prachayawarakorn et al (2002) studied the drying characteristics of shrimp in drying media at the temperature range of 120-180°C for superheated steam and of 70-140°C for hot air. They reported that the shrimp dried by the superheated steam shows a higher degree of shrimp quality.

Namsanguan et al (2005) performed the simulation of the drying process of shrimp using a superheated steam drying cabinet within the temperature range of 140-160°C. Jayasinghe et al (2006) studied the influence of temperature range of 50-90°C at 1, 2 and 3h drying time on convective drying kinetics of cooked shrimp. They found to be preferred method of processing that salting at 5% level followed by cooking for 20min and drying for 2h at 70°C. Niamnuy et al (2008a,b) studied thin-layer drying of shrimp in a jet spouted bed dryer and found that it is affected by drying air temperatures and air flow rate. They reported that drying shrimp at higher temperature led to lower astaxanthin degradation during storage than drying at lower temperatures. Visetsuntorn and Banjong (2010) studied the drying characteristics of shrimp in a batch convective dryer at 40-70ºC air temperatures.

Namsanguan et al (2004) and Namsanguan (2007) studied drying of shrimp at hybrid superheated steam and heat pump dryers and reported the same phenomenon in shrimp drying. Guochen et al (2009) have investigated dehydration property of shrimp undergoing heat-pump drying process. Tichangtong (2001) have studied effects of some operating parameters such as temperature, drying rates, specific energy consumption and drying efficiency on the viability of shrimp.

The influence of drying conditions upon the quality of shrimp has been investigated by Devahastin et al (2006) and Tapaneyasin et al (2005) in a jet-spouted bed dryer. In earlier work, Thanin and Salakphet (1998) performed batch drying experiments in spouted bed dryer and a combined microwave/spouted bed dryer of shrimp.

Most of the above studies examined on convective, superheated steam and heat-pump drying kinetics of shrimp. But, limited study concerning microwave drying kinetics of shrimp has been performed up to now.

Therefore, the aim of this study was to study the effects of microwave power on drying rate, specific energy consumption and drying efficiency of shrimp.

2. Materials and methods

2.1 Materials

Fresh shrimp used in this study were purchased from in Fish Bazar, Tehran, Iran and stored at refrigeration conditions (-2°C) prior to experiments. shrimp had an initial moisture content of 3.103 kg[H_2O]/kg[DM], which was determined by drying in a convective oven (Memmert, DO6836, Germany) at 103±1ºC for 4h (Guochen et al., 2009).

2.2 Experimental set-up

Fig.1 shows the microwave drying system. The drying apparatus used consisted of a laboratory microwave oven (M945, Samsung Electronics Ins) with features of 230V, 50 Hz with a frequency of 2450 MHz. Drying trial was carried out at four different microwave generation power being 200, 300, 400 and 500W. In the measurement of temperature, K type technical iron–constant thermocouple was used with multi-meter (ET-2230/2231, Minipa, China). About 45.95 g of shrimp was suspended beneath a digital balance (GF-600, A & D, JAPAN) into the microwave oven by using a mesh basket. The digital balance and was interfaced to a computer by a RS-232 cable, and the weight loss of the layer shrimp was recorded on-line every 15s throughout drying using software for the balance. Three replications of each experiment were performed according to a preset microwave output power and time schedule, and the data given are an average of these results.

2.3 Mathematical modeling

The moisture ratio (MR) was calculated using the following equation:

$$MR = \frac{M_t - M_e}{M_0 - M_e} \tag{1}$$

where MR is moisture ratio (dimensionless); M_t is moisture content at t (kg[H_2O]/kg[DM]); M_e is equilibrium moisture content (kg[H_2O]/kg[DM]); and M_0 is initial moisture content (kg[H_2O]/kg[DM]).

2.4 Effective moisture diffusivity

Fick's second law of the unsteady-state diffusion as in equation:

$$\frac{\partial M}{\partial t} = D_{eff} \nabla^2 M \tag{2}$$

The solution of Fick's second law in thin layer, with the assumptions of mass transfer being by diffusion and constant diffusion coefficient were as follows:

$$MR = \frac{8}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{(2n+1)^2}\exp\left(-(2n+1)^2\pi^2\frac{D_{eff}\,t}{H^2}\right) \quad (3)$$

where D_{eff} is effective diffusivity (m^2/s); t is drying time (s); and H is thickness of layer (m).

When the mass transfer Fourier number is greater than 0.2, equation (3) can be simplified to equation in the form:

$$t = \left(\frac{H^2}{\pi^2 D_{eff}}\right)\ln\left(\frac{8}{\pi^2}\frac{M_t}{M_0}\right) \quad (4)$$

The effective moisture diffusivity can be determined from the slope of the normalized plot of ln(MR) versus drying time.

2.5 Drying rate

The drying rate of the sample during drying process can be determined using the following equation:

$$DR = \frac{M_t - M_{t+\Delta t}}{\Delta t} \quad (5)$$

where DR is drying rate (kg[H_2O]/kg[DM] min).

2.6 Energy efficiency of microwave drying

The microwave drying efficiency was calculated as the ratio of heat energy utilised for evaporating water from the sample to the heat supplied by the microwave oven (Soysal, 2004; Yongsawatdigul and Gunasekaran, 1996).

$$\eta = \frac{m_w \lambda_w}{Pt} \quad (6)$$

where η is the microwave drying efficiency (%); m_w is the mass of evaporated water (kg); λ_w is the latent heat of vaporisation of water (J/kg) and P is the microwave power (W). The latent heat of vaporisation of water at the evaporating temperature (100ºC) was taken as 2257 (kJ/kg) (Hayes, 1987).

The specific energy consumption was calculated as the energy needed to evaporate a unit mass of water (Mousa and Farid, 2002; Soysal et al., 2006).

$$Q = \frac{Pt}{m_w} \quad (7)$$

where Q is the specific energy consumption (J/kg[H_2O]).

3. Results and discussion

3.1 Microwave drying kinetics

Drying of the shrimp started with an initial moisture content round 3.103(kg[H_2O]/kg[DM]) to the final moisture content of around 0.01(kg[H_2O]/kg[DM]). The variations of moisture content with drying time at different microwave powers are given in Fig. 2. As seen in Fig. 2, a reduction in drying time occurred with the increasing microwave power level. The drying time reduced by 2.94, 2.04 and 1.62 times in the drying treatment realized at 500, 400 and 300W microwave powers compared with the drying treatment realized at 200W microwave powers.

Fig. 3 shows the effect of microwave power on moisture ratio of shrimp. The increase in the microwave power decreased moisture ratio rapidly and decreased drying time. Microwave drying at 200, 300, 400 and 500W required 5.38, 3.25, 2.58 and 1.78 min, respectively for reducing the moisture ratio to 0.5. The drying times obtained in this present study was extremely low compared the results obtained in the previous studies given in literature. Therefore, convective drying is long and causes many undesirable changes in the shrimp.

As seen in Fig. 4, the drying rate increased rapidly at the beginning, attained a maximum value at about 2 minute followed by a gradual decrease. In general, it observed that drying rate reduces with time or with the reduction of moisture content. As mentioned earlier, the product's moisture content reduces over time. The drying process took place in the falling rate period. It was observed that, one of the main factors influencing the drying kinetics of the product is the drying microwave power during the falling rate drying period. Lahsasni et al. (2004) reported that the drying during the falling rate period is so governed by water diffusion in the solid.

Moisture movement to the surface and rate of moisture vaporisation from surface to air reduces with the reduction of moisture content in the product. For that reason, drying rate also reduces in time. As shown in Fig. 1, the high drying rate at high microwave power could be due to more heating energy which speeds up the movement of water molecules and results in higher moisture diffusivity. But, Hu et al. (2006) reported that too high microwave power drying has been associated with physical damages to the products. They found that it is difficult to control the quality of the dried products when higher power densities are used. Similar results have been reported by Varith et al. (2007); Akpinar et al. (2003); Togrul and Pehlivan (2002); Hu et al. (2006) and Alibas (2007).

3.2 Calculation of diffusion coefficient

The effective moisture diffusivities at different microwave powers are shown in Fig. 4. It can be seen that the values of D_{eff} increased greatly with increasing microwave power. The effective diffusivities of shrimp were 1.54×10^{-10}, 7.72×10^{-10}, 1.23×10^{-9} and 1.43×10^{-9} m^2/s at 200, 300, 400 and 500W, respectively. The values lie within the general range of 10^{-11}-$10^{-9} m^2/s$ for food materials (Madamba et al., 1996). The increase in microwave power resulted in rapid heating of the product, thus increasing the vapour pressure inside the product that made the diffusion of moisture towards the surface faster. The relationship between microwave power and moisture diffusivity can be represented as:

$$D_{eff} = 9\times10^{-15} P^2 + 1\times10^{-11} P - 2\times10^{-9} \qquad R^2 = 0.997 \tag{8}$$

where P is microwave power (W).

3.3 Energy efficiency of microwave drying

Change of microwave drying efficiency and specific energy consumption are shown in Fig. 5. According to Fig. 5, microwave drying efficiency and specific energy consumption decreased and increased with increase in microwave power from 4.174 to 3.237(MJ/kg[H_2O]) and 54.07 to 69.72%, respectively. As a result, the energy consumption in the drying processes carried out at low microwave power levels yielding longer drying period was determined to be in higher rates. This phenomenon agreed with the drying characteristics of many bioproducts under thin layer drying (Alibas, 2007; Araszkiewicz et al., 2004; Mousa and Farid, 2002; Soysal et al., 2004; Yongsawatdigul and Gunasekaran, 1996; Tulasidas et al., 1995). Araszkiewicz et al. (2004) and Mudgett (1982) reported that the dielectric properties of the product being dried are proportionally related to moisture content. Thus, intensity of heat generation or the ability of the product to absorb microwave energy decreases due to the reduction of moisture during the microwave drying process (Soysal et al.. 2004).

The specific energy consumption obtained in the drying process using 400W microwave power level was 5.88% higher than 300W microwave power level.

4. Conclusion

The thin layer drying behaviour of shrimp in a laboratory microwave dryer was examined at microwave powers from 200 to 500W. The following conclusions can be drawn from the study.

(1) Drying process took place only in the falling rate period for shrimp.

(2) Approximately 3.093 kg[H_2O]/kg[DM] of the moisture content was removed in this period.

(3) The drying time reduced by about 3.13 times on increasing microwave power from 200 to 500 W.

(4) Drying rate decreased with increasing drying time and decreasing moisture content.

(5) The effective diffusivity increases as microwave power increases.

(6) In contrast, increasing drying microwave power increased drying efficiency and decreased specific energy consumption.

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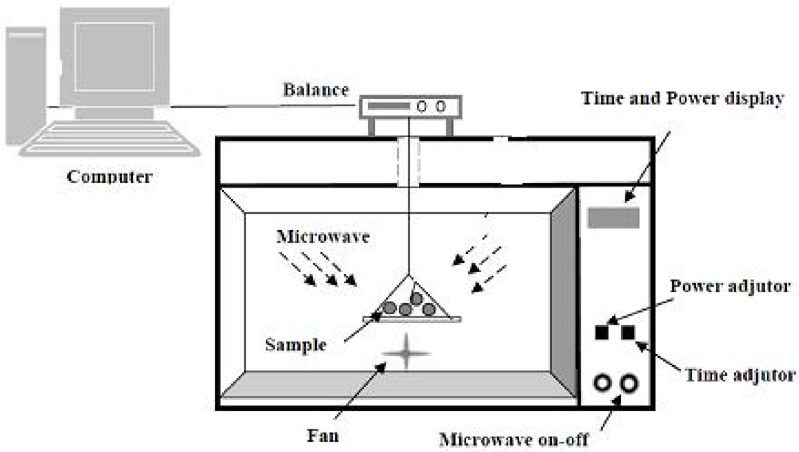

Figure 1. Diagram of microwave drying system

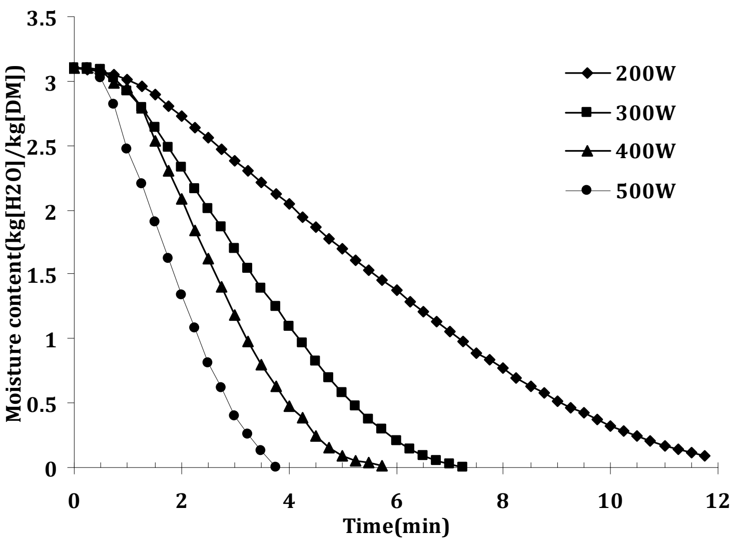

Figure 2. The relations of moisture content and drying time at different microwave powers

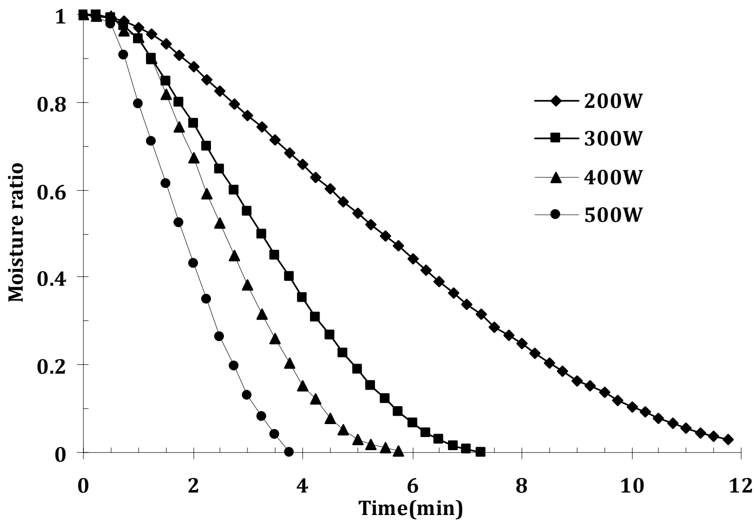

Figure 3. Drying curves of shrimp at different microwave powers

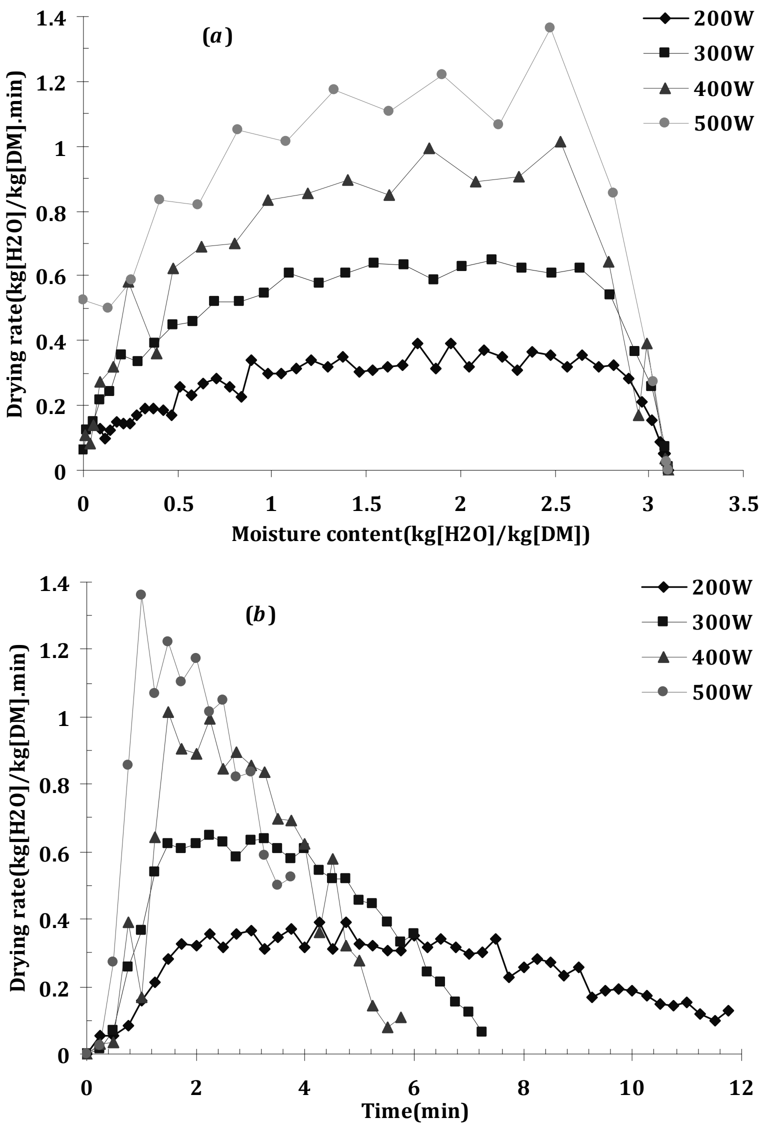

Figure 4. The relations of drying rate and (a) moisture content and (b) drying time at different microwave powers

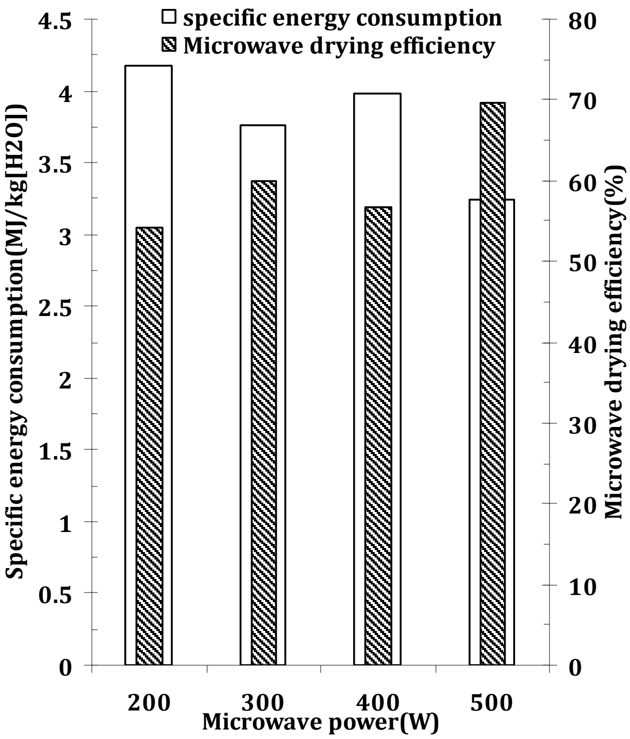

Figure 5. Microwave drying efficiency and specific energy consumption at different microwave powers

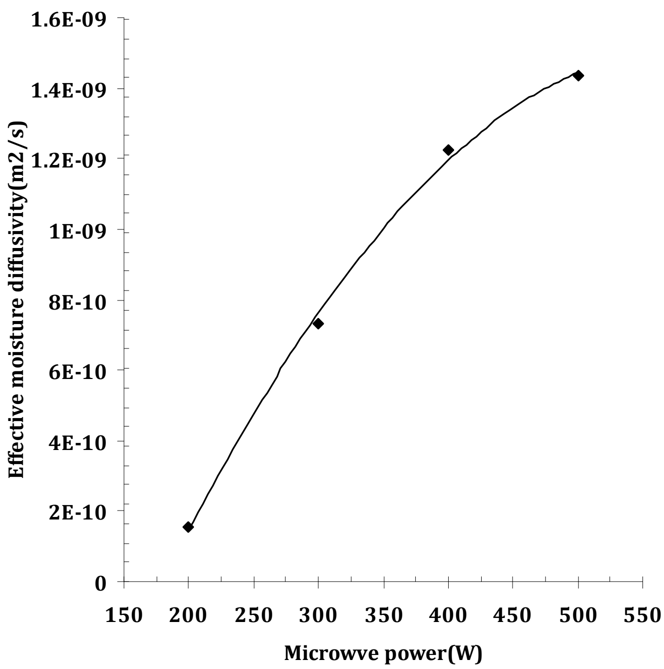

Figure 6. Effective diffusivities of shrimp dried at different microwave output powers