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By Hosain Darvishi, Asie Farhang, & Eisa Hazbavi
Islamic Azad University

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I. INTRODUCTION

Drying is probably the oldest and the most important method of food preservation practiced by humans. This process improves the food stability, since it reduces considerably the water and microbiological activity of the material and minimizes physical and chemical changes during its storage.

Dried shrimp is one of the most important exported marine products in many countries such as Thailand, China, Malaysia and United States. Most of the studies on drying kinetics of shrimp have focused on convective, superheated steam and heat-pump drying methods [1-8]. There is no available report regarding the effectiveness of intermittent microwave drying of shrimp compared to conventional drying techniques. One of the most important aspects of drying technology is the modeling of the drying process. Drying is a complex thermal process in which unsteady heat and moisture transfer occur simultaneously. From an engineering point of view, it is important to develop a better understanding of the controlling parameters of this complex process. Mathematical models of the drying processes are used for designing new or improving existing drying systems or even for the control of the drying process. Therefore, the objective of this work was to evaluate a suitable drying model for describing the microwave drying process of shrimp.

II. MATERIALS AND METHOD

The shrimp samples used in this study were obtained from a local fish market, Tehran, Iran during the summer season of 2010. The selected samples were cleaned with tap water to make samples free from dust and foreign materials. In order to preserve its original quality, they were stored in a refrigerator at 4 fC until drying experiments. The

Author ^a : Department of Engineering, Shahr-e-Rey Branch, Islamic Azad University, Tehran, Iran; E-mail : Hosaindarvishi@gmail.com, Tel: ++98 (21) 48292310

Author ^σ : Department of Veterinary Medicine, Tehran University, Tehran, Iran. E-mail: Asyiehfahrang@yahoo.com, Tel: ++98 (21)

Author ^ρ : Department of Engineering, Shahr-e-Rey Branch, Islamic Azad University, Tehran, Iran. E-mail : Hazbavi3000@yahoo.com, Tel: ++98 (21) 48292310

average initial moisture contents of the shrimp samples were found to be 3.103% (d.b.), as determined by using convective oven at at 103ffi1 ° C for 4h [3].

The drying was done in a microwave dryer developed for this purpose. The schematic of the experimental microwave drying set-up is given in Fig. 1. The dryer consists of a microwave oven M945, Samsung Electronics Ins, a variable speed fan and a digital balance. The dimensions of the microwave cavity were 327×370×207 mm.

The microwave oven was operated by a control terminal which could control both microwave power level and emission time. The microwave oven was operated by a control terminal which could control both microwave power level and emission time. In order to weigh the samples without taking them out of the oven, a weighing system was integrated to the oven. A digital balance (GF-600, A & D, Japan) which has a sensitivity of 0.01 g and a plastic disc was mounted to the bottom of the microwave oven. The disc was rotated at 5 rpm on a ball bearing shaft driven by an electrical motor. The presence of the rotating disc was necessary to obtain homogeneous drying and to decrease the level of the reflected microwaves on to the magnetrons. The oven has ventilation holes on the top as well as on the bottom. Air velocity was kept at a constant value of 1 m/s with an accuracy of ffi0.1 m/s measured with a Vane Probe anemometer AM- 4202 Lutron flowed perpendicular to the bed. Drying experiments were carried out with 200, 300, 400 and 500 W microwave power levels to investigate the effects of microwave power on drying of shrimp. Samples (46 ffi 0.5 g) were placed in a single layer on a rotating glass plate in the oven. Moisture loss of the samples was recorded by means of the balance at 15 s intervals until no discernible weight change was observed. Rotating was stopped by pulling back the driving disc when recording the weight data.

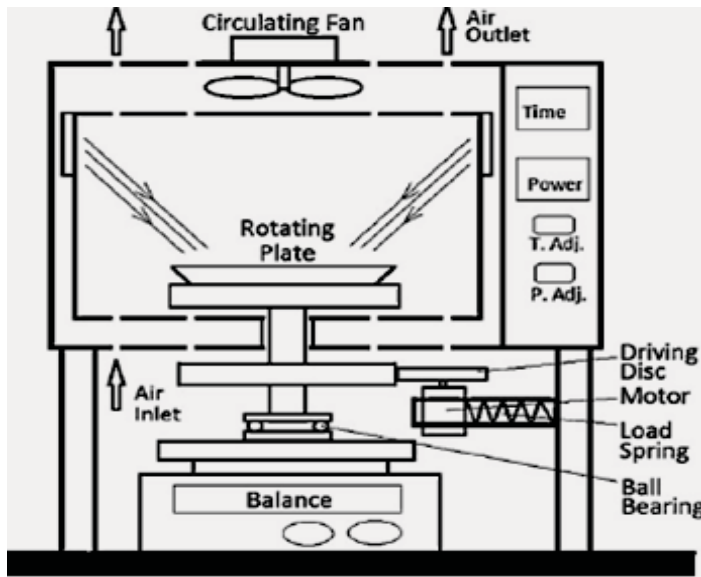


Fig. 1 : Schematic illustration of the microwave drying set-up

The moisture content of drying sample at time t can be transformed to be moisture ratio (MR):

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

where M_t , M_0 and M_e are moisture content at any time of drying (kg water/kg dry matter), initial moisture content (kg water/kg dry matter) and equilibrium moisture content (kg water/kg dry matter), respectively.

The moisture ratio was simplified to Mt/M_0 instead of Eq. (1) by some investigators [9-11] due to the continuous fluctuation of the relative humidity of the drying air during microwave drying process.

Table 1: Mathematical models given by various authors for drying curves

Model name	Model	Refe
Lewis	$MR = \exp(-kt)$	[16]
Henderson and Pabis	$MR = a \exp(-kt)$	[17]
Page	$MR = \exp(-kt^n)$	[18]
Wang and Singh	$MR = 1 + bt + at^2$	[19]
Parabolic	$MR = c + bt + at^2$	[20]
Logarithmic	$MR = a \exp(-kt) + b$	[11]
Midilli	$MR = a \exp(-kt^n) + bt$	[21]

where, k is the drying constant and a, b, n are equation constants.

The drying data obtained were fitted to seven thin-layer drying models detailed in Table 1 using the nonlinear least squares regression analysis. Statistical analyses of the experimental data were performed by using the software SPSS 17.0. The coefficient of determination (R^2) is one of the primary criteria for selecting the best model to define the drying curves. In addition to R^2 , reduced chi-square (χ^2) and root mean square error (RMSE) are used to determine the quality of the fit. These parameters can be calculated as follows:

$$R^2 = 1 - \frac{\sum_{i=1}^N (MR_{pre,i} - MR_{exp,i})^2}{\sum_{i=1}^N (MR_{pre,i} - MR_{exp,i})^2} \tag{2}$$

$$\chi^2 = \frac{\sum_{i=1}^N (MR_{pre,i} - MR_{exp,i})^2}{N - z} \tag{3}$$

$$RMSE = \left(\frac{\sum_{i=1}^N (MR_{pre,i} - MR_{exp,i})^2}{N} \right)^{\frac{1}{2}} \tag{4}$$

where $MR_{exp,i}$ is experimental moisture ratio; $MR_{pre,i}$ is predicted moisture ratio; N is number of observations; z is number of constants. The best model describing the drying characteristics of samples was chosen as the one with the highest coefficient of determination, the least reduced chi square, root mean square error and mean relative percent error [12-15].

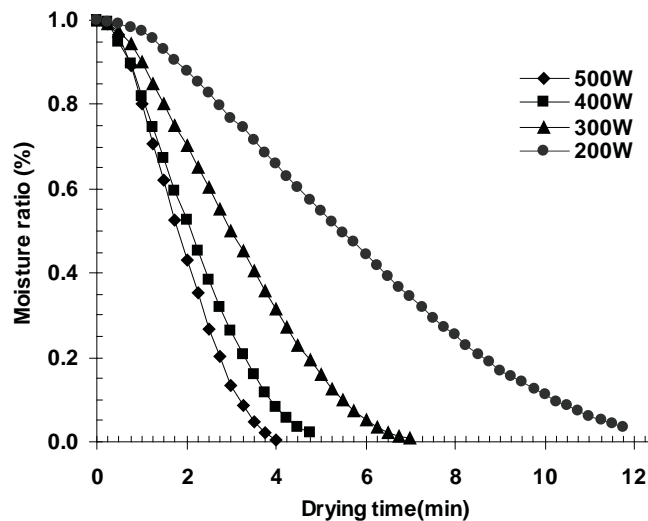


Fig 2 : Moisture ratio versus drying time of shrimp at different microwave powers

III. RESULTS AND DISCUSSION

The changes in moisture ratio with drying time of shrimp samples in microwave drying are presented in Fig. 2. According to the results in Fig. 2, the drying microwave power a significant effect on the moisture content of the shrimp samples as expected. The results showed that drying time decreased greatly when drying temperature increased. The drying time required to reach the final moisture content of samples were 11.75, 7, 4.75 and 4 min at the microwave powers of 200, 300, 400 and 500W, respectively. The results indicates that mass transfer within the sample was more rapid during higher microwave power heating because more heat was generated within the sample creating a

Model no	P (W)	Model constants	R2	χ^2	RMSE
Lewis	500	k=0.7917	0.7454	0.0471	0.2105
	400	k=0.5803	0.8447	0.0265	0.1586
	300	k=0.4531	0.7816	0.0351	0.1840
	200	k=0.2019	0.8508	0.0203	0.1409
Henderson and Pabis	500	a= 2.254, k=1.0873	0.8297	0.1599	0.3756
	400	a= 1.7673, k=0.7556	0.9118	0.0549	0.2224
	300	a= 2.1411, k=0.6133	0.8614	0.1053	0.3131
	200	a= 1.6307, k=0.2636	0.9188	0.0295	0.1682
Page	500	k=0.203, n=2.077	0.999	0.0002	0.0123
	400	k=0.182, n=1.847	0.999	0.0001	0.0109
	300	k=0.092, n=1.865	0.998	0.0003	0.0158
	200	k=0.033, n=1.804	0.999	0.0001	0.0116
Wang and Singh	500	a=0.0002, b= - 0.2704	0.9759	0.0034	0.0552
	400	a=0.0068, b= - 0.2521	0.9834	0.0021	0.0437
	300	a= 0.0035, b= - 0.1772	0.9847	0.0019	0.0422
	200	a= 0.0003, b=- 0.0913	0.9869	0.0014	0.0369
Parabolic	500	a= 0.019, b= - 0.3636, c= 1.0962	0.9861	0.0021	0.0419
	400	a= 0.0185, b= - 0.321, c= 1.084	0.9917	0.0011	0.0310
	300	a= 0.0091, b= - 0.2252, c= 1.086	0.9927	0.0009	0.0291
	200	a= 0.0022, b= - 0.1185, c= 1.081	0.9945	0.0006	0.0239
Logarithmic	500	k= 0.115, a=3.125, b= - 2.033	0.985	0.0022	0.0429
	400	k= 0.141, a=2.284, b= - 1.204	0.991	0.0013	0.0329
	300	k= 0.101, a= 2.239, b= - 1.156	0.992	0.0011	0.0314
	200	k= 0.044, a=2.711, b=- 1.632	0.997	0.0007	0.0250
Midilli	500	k= 0.207, a= 1.008, b= -0.012, n=1.944	0.999	0.00006	0.0067
	400	k= 0.187, a= 1.007, b= -0.011, n=1.718	0.999	0.00003	0.0053
	300	k= 0.095, a= 1.002, b= -0.01, n=1.718	0.999	0.00011	0.0096
	200	k= 0.038, a= 1.008, b= -0.006, n=1.657	0.999	0.00005	0.0066

large vapor pressure difference between the centre and the surface of the product due to characteristic microwave volumetric heating.

The statistical results from models are summarised in Tables 2. The best model describing the thin-layer drying characteristics of shrimp was chosen as the one with the highest R² values and the lowest X² and RMSE values. The R² for Henderson and Pabis, Logarithmic, Wang and Singh, Page, and Midilli models were all above 0.99, and that for Lewis model was lower, but still above 0.745. The statistical parameter estimations showed that R², X² and RMSE values were ranged from 0.7454 to 0.9999, 0.00003 to 0.1599, and 0.0053 to 0.3756, respectively. Of all the models tested, the Midilli model gives the highest value of R2 and the lowest values of X² and RMSE. Fig. 3 compares

experimental data with those predicted with the Midilli model for shrimp samples at 200, 300, 400 and 500W. The prediction using the model showed MR values banded along the straight line, which showed the suitability of these models in describing drying characteristics of shrimp.

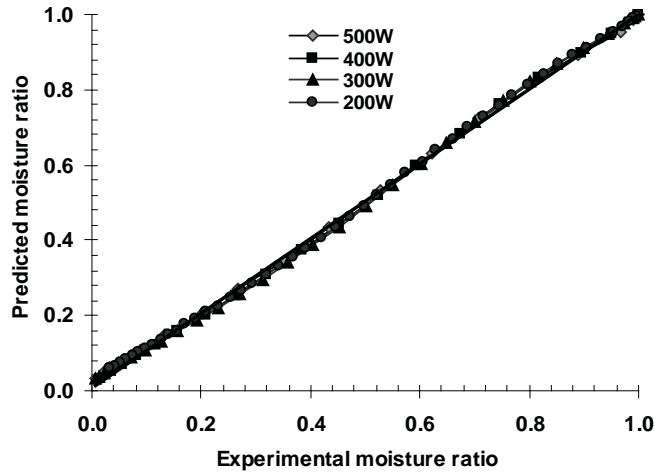


Fig 3: Experimental versus predicted moisture ratio (MR) values for shrimp drying

It was determined that the value of k increased with the increase in the microwave power. This data indicates that with increase in microwave power drying curve becomes steeper indicating faster drying of the product. A similar trend was observed by Ozkan et al. [22] for spinach; Sharma and Prasad [20] for garlic cloves.

In this study, as the temperature is not measurable variable in the standard microwave oven used for drying process, the Arrhenius equation was used in a modified form to illustrate the relationship between the kinetic rate constant and the ratio of the microwave output power to sample amount instead of the temperature for calculation of the activation energy. After evaluation of the data, the dependence of the kinetic rate constant on the ratio of microwave output power to sample amount was represented with an exponential equation (6) derived by Ozbek and Dadali [23]:

$$k = k_0 \exp\left(\frac{-E_a \cdot m}{P}\right) \tag{6}$$

where k is the drying rate constant obtained by using Midilli model (1/min), k_0 is the pre-exponential constant (1/min), E_a is the activation energy (W/g), P is the microwave output power (W) and m is the mass of raw sample (g). The values of k versus m/P shown in Fig. 4 accurately fit to Eq. (6) with coefficient of determination (R^2) of 0.9869. Then, k_0 and E_a values were estimated as 0.722 (1/min) and 12.834W/g.

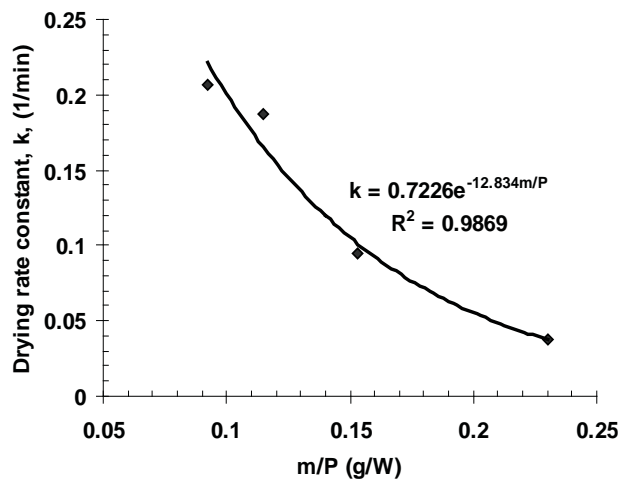


Fig 4: The relationship between the values of drying rate constant versus sample amount/power

22. Ozkan A.I., Akbudak B. and Akbudak N; Microwave drying characteristics of spinach. J Food Eng, 78(2007), 577-583
 23. Ozbek B. and Dadali G; Thin-layer drying characteristics and modelling of mint leaves undergoing microwave treatment. J Food Eng, 83(2007), 541-549

Ref.

IV. CONCLUSION

The drying kinetics of shrimp was investigated in a microwave dryer as a single layer at the drying microwave powers of 200, 300, 400 and 500 W. Based on non-linear regression analysis, the Midilli model was considered adequate to describe the thin-layer drying behavior of shrimp. The drying rate constant increased with increasing microwave power and it followed an Arrhenius relationship. The activation energy for moisture diffusion was found to be 12.834W/g.

REFERENCES RÉFÉRENCES REFERENCIAS

1. Namsanguan Y., Tia W., Devahastin S., and Soponronnarit, S; Drying kinetics and quality of shrimp undergoing different two-stage drying processes. *Dry Tech*, 22(4) (2004), 759-778.
2. Namsanguan, Y; Drying of shrimp using hybrid superheated steam and heat pump dryers, Thies Ph.D, King Mongkut's University Technology Thonburi, Bangkok, 2007.
3. Guochen, Z, Arason, S, and Arnason, S. A; Dehydration property of shrimp (*Pandalus borealis*) undergoing heat-pump drying process. *International Journal Agriculture & Biology Engineering*, 2(4) (2009), 92-97.
4. Niamnuy, C, Devahasstin, S, Soponronnarit, S, and Raghavan, G. S. V; Kinetics of astaxanthin degradation and color changes of dried shrimp during storage. *J Food Eng*, 87(2008), 591-600.
5. Niamnuy, C, Devahasstin, S, Soponronnarit, S, and Raghavan, G. S. V; Modeling coupled transport phenomena and mechanical deformation of shrimp during drying in a jet spouted bed dryer. *Chem Eng Sci*, 63(2008), 5503-5512
6. Prachayawarakorn, S, Soponronnarit, C, Wetchacama, S, and Jaisut, D; Desorption isotherms and drying characteristics of shrimp in superheated steam and hot air. *Dry Tech*, 20(2002), 669-684
7. Namsanguan, Y, Tichangton, S, Tia, W, Soponronnarit, S, and Devahastin, S; Simulation of a mixed air and superheated steam drying system. *DryTech*, 23(2005), 25-248
8. Jayasinghe, P. S, Jayasinghe, J. M. P. K, and Galappaththi, C. P; Influence of different processing methods on quality and shelf life of dried shrimp. *Sri Lanka Journal Aquatic Science*, 11(2006), 85-91
9. Doymaz I. Sun drying of figs: an experimental study. *J Food Eng* 71(2005), 403–407
10. Kingsly RP, Goyal RK, Manikantan MR, Ilyas SM; Effects of pretreatments and drying air temperature on drying behavior of peach slice. *Int J Food Sci Technol*, 42(2007), 65–69
11. Akpınar EK; Mathematical modeling and experimental investigation on sun and solar drying of white mulberry. *J Mec Sci Technol*, 22(2008), 1544–1553
12. Goyal RK, Mujjeb O, Bhargava VK; Mathematical modeling of thin layer drying kinetics of apple in tunnel dryer. *Int J Food Eng* 4(8)(2008), Article 8
13. Sobukola OP, Dairo OU, Odunewu AV; Convective hot air drying of blanched yam slices. *Int J Food Sci Technol*, 43(2008), 1233–1238
14. Menges HO, Ertekin C; Mathematical modeling of thin layer drying of golden apples. *J Food Eng*, 77 (2006), 119–125
15. Caglar A, Togrul IT, Togrul H; Moisture and thermal diffusivity of seedless grape under infrared drying. *Food Bioprod Process*, 87(2009), 292–300

16. Bruce D.M; Exposed-layer barley drying, three models fitted to new data up to 150 fC. *J Agric Eng Res.* 32(1985), 337–347
17. Henderson S.M. and Pabis, S; Grain drying theory I: temperature effect on drying coefficient. *J Agric Eng Res*, 6 (1961), 169–174
18. Vega-Gálvez A., Miranda M., Diaz L.P., Lopez L., Rodruguez K. and Di Scala K; Effective moisture diffusivity determination and mathematical modelling of the drying curves of the olive-waste cake. *Bioresource Technology*, 101 (2010), 7265-7270
19. Wang C.Y. and Sing R.P; A single layer drying equation for rough rice. paper no.78-3001, ASAE, St Joseph, MI, 1987.
20. Sharma G.P. and Prasad S; Drying of garlic (*Allium sativum*) cloves by microwave-hot air combination. *J Food Eng*, 50(2001), 99-105
21. Midilli A, Kucuk H, Yapar Z; A new model for single layer drying. *Dry Tech*, 20(2002); 1503–1513
22. Ozkan A.I., Akbudak B. and Akbudak N; Microwave drying characteristics of spinach. *J Food Eng*, 78(2007), 577–583
23. Ozbek B. and Dadali G; Thin-layer drying characteristics and modelling of mint leaves undergoing microwave treatment. *J Food Eng*, 83(2007), 541-549



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