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Microwave Drying of Bitter Guard samples: Mass Transfer Parameter Estimation using Bi-G Correlations

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ABSTRACT -- Bitter guard samples were pretreated by blanching in hot water and osmotic dehydrated by using the mixture of 10% Nacl and 5%Citric acid solution. The initial moisture content of the untreated, blanched and osmotic dehydrated samples was 92.3%wet basis (w.b.), 89.8% (w.b.) and 86.05% (w.b.) respectively. The untreated and pretreated samples were subjected to microwave drying at five different microwave powers of 900, 720, 540, 360 and 180watts (W). The moisture loss with time was recorded for determining the drying characteristics. The dimensionless moisture content was used to calculate the drying coefficient and the lag factor by using the correlation from literature. These constants were used to determine the mass Biot number. The dimensionless moisture ratio was also determined by using Bi-G correlation drying model. The experimental moisture ratio was in good agreement with the predicted moisture ratio. The moisture diffusivity and the mass transfer coefficient were also obtained from Bi-G correlation drying model.

Keywords: drying coefficient, Biot number, moisture diffusivity, mass transfer coefficient, Bi-G correlation.

1. INTRODUCTION

Drying is a very complicated process involving simultaneous heat and mass transfer under transient conditions. Understanding the heat and mass transfer in the product will help to improve drying process parameters and hence the quality. A number of internal and external parameters influence drying behavior [1]. Microwave drying had proved to be successful for many industrial applications, with the unique heating mechanisms providing benefits such as improved product quality, increased energy efficiency and reduced drying times [2-3]. A better understanding of heat and mass transfer during drying, followed by the formulation of adequate mathematical models of food drying, contributes to the optimization of this process, and improves product quality [4].
Dincer and Dost [5] had carried out the work to characterize the mass transfer during drying. Drying parameters like drying coefficient (S) and lag factor (G) were defined based on the analogy between cooling and drying profiles, both of which exhibit an exponential form with time. The model had been used to determine the mass transfer properties for the drying of wood products [6]. The Bi-G correlation developed by Dincer and Hussain [7] had proved to be adequate in predicting the moisture distribution and was suitable to be used in practical drying applications.

However, no work had been reported in literature on determination of mass transfer properties for microwave drying of pre treated and untreated bitter guard samples. Therefore the objective of the present study is to determine the moisture transfer properties like moisture diffusivity and mass transfer coefficient using the Bi-G correlation at five different microwave powers. Subsequently, determine the dimensionless moisture ratio by using the Bi-G correlation drying model and to compare with that determined from the microwave drying experiments.

2. MATERIALS AND METHODS

2.1 Experimental set up

Bitter guard was procured from the local market and cut into circular disc shaped slices of thickness 5mm and was stored in the refrigerator after packing in airtight poly ethylene bags. The drying was carried out in a domestic microwave oven (LG, Model no MG 607 APR GRILL). The power of the microwave could be varied between 180 to 900W. The moisture loss with time was recorded using the electronic balance of accuracy 0.01g. The samples were dried to equilibrium.

2.2 Experimental procedure

Initial moisture content (IMC) of untreated, blanched and osmotic dehydrated bitter guard samples were determined by using the oven method, keeping the sample in the oven for 24 hours at 105°C [8] and noting down the weight at regular time intervals. The samples were kept in desiccator and cooled to room temperature before weighing, each time. The IMC of the untreated bitter guard samples was found to be 92.3%.w.b. Pre treatments like osmotic treatment and blanching was done in order to dewater the bitter guard sample and to reduce the drying time. Osmotic treatment was done by dipping the bitter guard sample in 10%NaCl/5%citric acid solution for 24 hours and the IMC was found to be 86.05%.w.b. Blanching of bitter guard was carried out in hot water for 2 minutes and the IMC was 89.8%.w.b. The microwave drying characteristics of pre/untreated samples of bitter guard were carried out at five microwave powers, 900W, 720W, 540W, 360W, 180W and the moisture loss with time were recorded at regular intervals of time.

2.3 Data analysis

A simple correlation was developed for prediction of the moisture transfer parameters of the products subjected to the drying. The sample to be dried was assumed to be as an infinite slab, the moisture diffusion was in the direction of thickness [6]. An exponential form was assumed to the drying model, the dimensionless moisture content (Ø) was defined in terms of the drying coefficient (S) and lag factor (G), given in equation (1).

$$Ø = G \exp(-St) \quad (1)$$

The lag factor,G indicates the magnitude of both the internal and external resistance to the moisture transfer from the object as a function of the Biot number. The drying coefficient is a parameter describing the drying capability of the solid object and has a direct effect on the moisture diffusivity and an indirect effect on the moisture transfer coefficient.

The experimental data obtained was used to determine the moisture ratio. The dimensionless moisture ratio was given by equation (2).

$$MR = \frac{M - Me}{Mo - Me} \quad (2)$$

where MR is the dimensionless moisture ratio, M is the moisture at any time, M_0 is the initial moisture content in kg H_2o/kg wet mass. However MR is simplified to M/M_0 instead of equation II, due to the continuous fluctuation of relative humidity of the drying air during the drying process [9].

Using the drying coefficient (S) and lag factor (G), moisture transfer properties like moisture transfer coefficient (K), moisture diffusivity (D) and Biot number (Bi) could be estimated by using the equations (3), (4) and (5) respectively.

$$K = \frac{DBi}{Y} \quad (3)$$

$$D = \frac{SY^2}{\mu_1^2} \quad (4)$$

Where Y is the half thickness of the slab, μ_1 is the root of the characteristic equation

$$Bi = 0.0576G^{26.7} \quad (5)$$

To compute the moisture diffusivity (D), the coefficient μ_1, was determined by the root of characteristic equation. A simplified equation for roots of characteristic equation was developed in drying application [10] and is given by the equation (6).

$$\mu_1 = -419.24G^4 + 2013.8G^3 - 3615.8G^2 + 2880.3G - 858.94 \quad (6)$$

For verification of the applicability of the model, a dimensionless moisture distribution was calculated by using the equations (7), (8), (9) and (10).

$$Ø = A_1B_1 \quad (7)$$

Where $A_1 = G = \exp[(0.2533Bi)/(1.3+Bi)]$, (8)

$B_1 = \exp(-\mu_1^2F_0)$, (9)

$F_0 = Dt/Y^2$ (10)

Where, F_0 is the Fourier number, [5].

3. Results And Discussion

The microwave drying characteristics of pre/untreated bitter guard was studied using the experimental drying profile. It indicated that the drying time decreased for pre treated samples and for higher microwave powers. The obtained dimensionless moisture distribution against drying time is regressed in the form of equation (1) using the least square curve fitting method. Thus, the lag factor and drying coefficient were determined for untreated and pre treated bitter guard samples and were presented in Table 1. The Biot number was calculated using equation (5). The values of, moisture diffusivities and mass transfer coefficients at different microwave powers for pre/untreated bitter guard were presented in Table 2.From the results, it was observed that the diffusivity was higher for microwave drying of pre treated bitter guard. The predicted dimensionless moisture content was determined using the equation (7). A_1 was calculated from the equation (8). In order to obtain B_1, Fourier number was calculated from equation (10) and B_1 was determined from equation (9). The experimental data was compared with the predicted data and was presented in Figure 1, Figure 2 and Figure 3 for untreated, blanched and osmotic dehydrated bitter guard samples respectively. The predicted results agreed with the experimental moisture content data with reasonable accuracy.

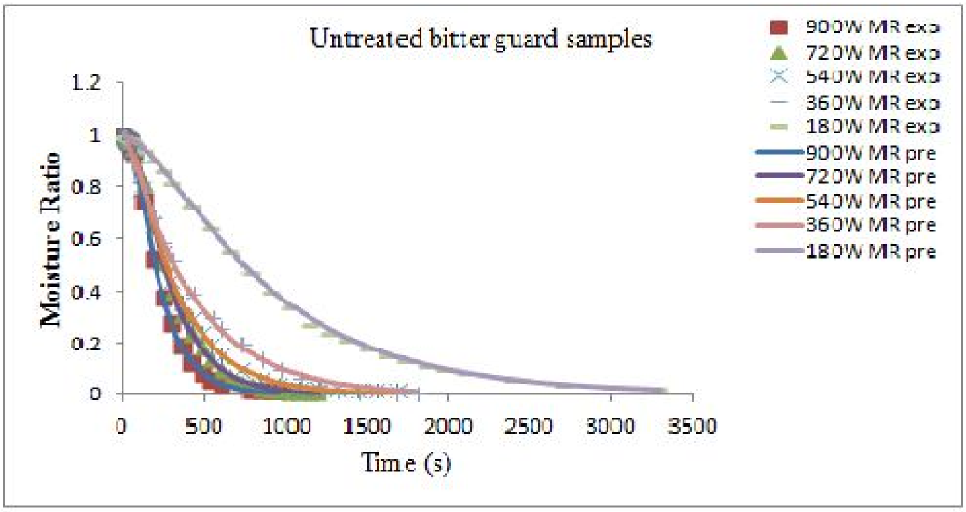

Figure 1: *Experimental and predicted moisture ratio vs time for untreated bitter guard samples at microwave powers of 900,720, 540,360 and 180W.*

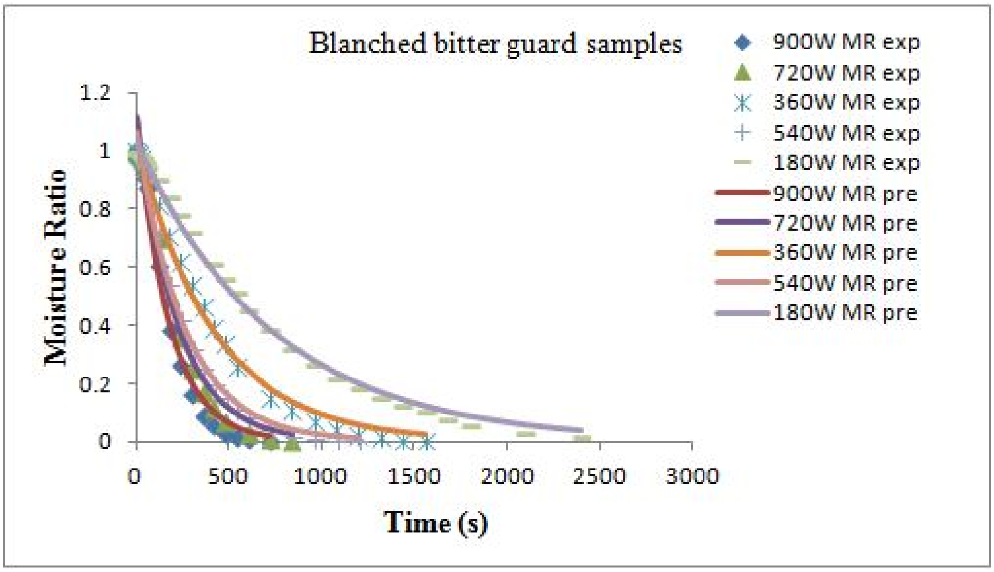

Figure 2: *Experimental and predicted moisture ratio vs time for blanched bitter guard samples at microwave powers of 900,720, 540,360 and 180W.*

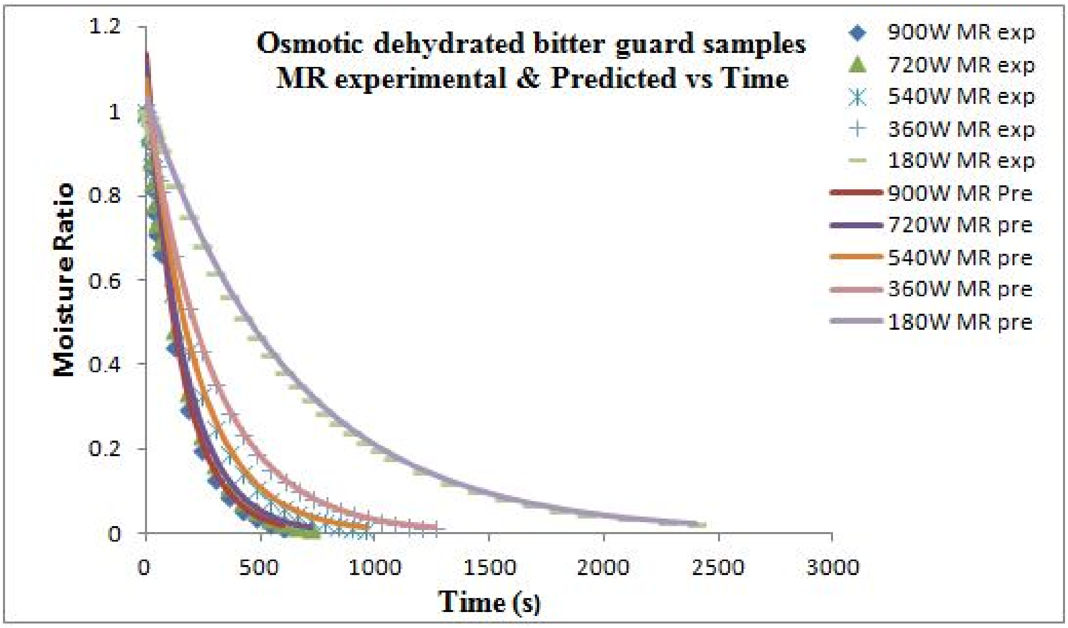

Figure 3: *Experimental and predicted moisture ratio vs time for osmotic dehydrated bitter guard samples at microwave powers of 900,720, 540,360 and 180W.*

Table 1
The lag factors and drying coefficients for Microwave thin layer drying of untreated and pre treated bitter guard.

Powers	Experiments	Lag factor,G(1/s)	Drying coefficient,S
900 W	Untreated	1.11	0.004392
	10%NaCl/5%citric acid solution treated	1.124	0.006754
	Blanched	1.113	0.005688
720 W	Untreated	1.091	0.00344
	10%NaCl/5%citric acid solution treated	1.111	0.005995
	Blanched	1.108	0.004597
540 W	Untreated	1.069	0.002992
	10%NaCl/5%citric acid solution treated	1.086	0.004643
	Blanched	1.075	0.003866
360 W	Untreated	1.036	0.002338
	10%NaCl/5%citric acid solution treated	1.046	0.003475
	Blanched	1.049	0.002414
180 W	Untreated	1.051	0.001073
	10%NaCl/5%citric acid solution treated	1.045	0.001602
	Blanched	1.039	0.001364

Table 2
Moisture diffusivity, moisture transfer coefficient and Biot numbers for microwave drying of untreated and pre treated Bitter guard.

Powers	Experiments	μ_1	Bi*10^{-3}	D(m^2/s)	K (m/s)
900 W	Untreated	0.865289	0.934428373	3.67*10^{-08}	1.37*10^{-05}
	10%NaCl/5%citricacid solution treated	0.91109009	1.30581903	5.09*10^{-08}	2.66*10^{-05}
	Blanched	0.87532249	1.00425354	4.64*10^{-08}	1.86*10^{-05}
720W	Untreated	0.796858	0.58930934	3.39*10^{-08}	6.98*10^{-06}
	10%NaCl/5%citricacid solution treated	0.868651	0.957167309	4.97*10^{-08}	7.29*10^{-06}
	Blanched	0.85851	0.890500332	3.28*10^{-08}	4.19*10^{-06}
540W	Untreated	0.700084	0.342079629	3.82*10^{-08}	5.22*10^{-06}
	10%NaCl/5%citricacid solution treated	0.7769	0.521289308	4.81*10^{-08}	1.00*10^{-05}
	Blanched	0.728989	0.397217596	4.55*10^{-08}	7.22*10^{-06}
360W	Untreated	0.491619	0.148090757	6.05*10^{-09}	3.58*10^{-06}
	10%NaCl/5%citricacid solution treated	0.565248	0.191389655	6.79*10^{-09}	5.20*10^{-06}
	Blanched	0.585366	0.206598906	4.41*10^{-09}	3.64*10^{-06}
180W	Untreated	0.598312	0.217377706	1.87*10^{-09}	1.63*10^{-06}
	10%NaCl/5%citricacid solution treated	0.558349	0.186563825	3.21*10^{-09}	2.39*10^{-06}
	Blanched	0.514824	0.15997702	3.22*10^{-09}	2.06*10^{-06}

4. CONCLUSIONS

Moisture diffusivity and moisture transfer coefficient for microwave drying of untreated and pre treated bitter guard samples were determined at five microwave powers by using the Bi-G correlation. This method had proved to be simple and accurate for determining the moisture transfer parameters. The predicted moisture ratio was in good agreement with the experimental data.

Nomenclature			
A_1	Constant	*w.b*	Wet basis
B_1	Constant	*Greek symbols*	
Bi	Biot number	Ø	Dimensionless moisture content
D	Moisture diffusivity(m^2/s)	μ_1	Root of the transcendental characteristic equation (dimensionless)
F_0	Fourier number	*Subscripts*	
G	Lag factor (dimensionless)	*1*	First characteristic value
K	Mass transfer coefficient (m/s)	*e*	Equilibrium
S	Drying coefficient (1/s)	*0*	initial
T	Time (s)		
M	Moisture content (kg/kg, wet basis)		
Y	Characteristics dimension (slab half-thickness (m))		
IMC	Initial moisture content (kg/kg, wet basis)		

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