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Analysis Of Mass Transfer During Microwave Drying Of Yam Slabs

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Abstract: - This paper presents an experimental approach to the drying of yam slabs using microwave. The reduction in the mass of the yam slab with time at medium low conditions was investigated. A theoretical model to describe the drying of the yam slab in microwave was developed and validated using the experimental data. The effective diffusivity of water molecules in yam slab in medium low power condition of the microwave oven was estimated to be 5.83 x 10^{-8} m^2/s. Simulations of the model reveals that the microwave drying of yam slabs is very sensitive to the thickness of the yam slab and is independent of the moisture content and initial mass of the yam slab. As the thickness of the yam slab increases the rate of drying decreases and therefore the time for complete drying increases.

Keywords: - *Effective diffusivity, Microwave Drying, Model Development, Moisture content.*

I. INTRODUCTION

Drying of food products is essential for the preservation of the food product for long periods of time due to the fact that micro-organisms and food enzymes need moisture to function effectively causing food spoilage. Drying processes for food products include sun drying, hot air drying, freeze-drying, flash freezing and microwave drying.

Microwaves are short high frequency radio waves lying between infrared and conventional radio waves. Microwave drying is a rapid dehydration technique that can be applied to specific foods. The microwaves agitate the water molecules in the food causing them to vibrate and produce heat which drives the drying process. Microwave drying is rapid, uniform, energy efficient and space saving [1, 2, 3, 4

Zogzas *et al*. [5], presented a review of reported experimental moisture diffusivity data in food materials. Krokida *et al*. [6], investigated the effects of the drying methods on the colour of the obtained products and found that the colour characteristics were significantly affected by the drying methods employed. Sharma and Prasad [7] determined the effective moisture diffusivity of garlic cloves during a microwave convective drying process. They also investigated its dependence on factors such as microwave power, air temperature and air velocity. McMinn *et al*. [8] investigated the mass transfer characteristics for potato slabs and cylinders subjected to natural convective and microwave convective drying by adopting the analytical model proposed by Dincer and Dost [9,10]. They showed that the model accurately described the drying process of Potato slabs and that the power of the microwave has the main effect in drying. The model developed by Dincer and Dost [9, 10] was not developed from experimental data for microwave drying of food products although when applied to the drying of Potato slabs by McMinn *et al*. [8] it was accurate. Sharma and Prasad [7], investigation was limited to drying of garlic cloves using microwave convective drying process. In this paper, experimental data from a microwave drying system are used to determine the mass transfer characteristic for slab yam samples. An accurate theoretical model for the microwave drying of yam slabs is developed and validated using the experimental data. The effective diffusivity of water molecules in yam slab in medium low power condition of the microwave oven was estimated to be 5.83 x 10^{-8} m^2/s. Simulations of the model reveals that the microwave drying of yam slabs is very sensitive to the thickness of the yam slab and is independent of the moisture content and initial mass of the yam slab. As the thickness of the yam slab increases the rate of drying decreases and therefore the time for complete drying increases.

II. EXPERIMENTATION AND THEORETICAL FORMULATION.

The key Apparatus used for the experiment includes; Microwave oven, Weighing balance, Knife, crucible and scale rule. The materials used for the experiment are the yam tubers and water.

1.1 Experimental Procedure

Wash the yam tubers with water. Peel the yam tubers using knife. Cut the yam to the required thickness (1 cm) using knife and scale rule. Weigh the yam slab to obtain the initial weight using weighing balance. Switch on the microwave oven at medium low operating condition for 5 minutes. Put the yam slab on the crucible into the microwave oven and allow for 2 minutes. Weigh the yam slab from the microwave oven using the weighing balance. Repeat steps 6 and 7 until there is no significant change in weight of the yam slab or burning is observed.

1.2 Model Development

The model for microwave drying of yam was done based on the following assumptions:
Initially there is uniform distribution of moisture in the yam.
There is zero concentration of moisture on the surface of the yam.
Drying occurs only from the upper surface of the yam slab on the crucible.
No reaction or burning of the yam slab takes place during the drying process.
Transfer of water molecules from the yam slab occurs in the vertical direction only.

Applying the principle of conservation of mass given as:

Rate of Accumulation of water within the yam slab	=	Rate of Input of water in yam slab	-	Rate of Output of water from yam slab	+	Rate of Generation of water within the yam slab	1

Substituting appropriate parameters in equation 1 for the yam slab yields:

$$\frac{\partial C_w}{\partial t} = D\frac{\partial^2 C_w}{\partial y^2} \qquad 2$$

where, C_w is moisture content, t is time, D is effective diffusivity and y is distance in the vertical direction within the yam slab.
The moisture content is given by

$$C_w = \frac{w - w_e}{w_e} \qquad 3$$

where, w is mass of yam slab and w_e is the mass of yam slab when drying is complete.
The following boundary conditions are applied to solve equation (2)

$$C_w(0,t) = 0 \text{ for } 0 < t < \infty \qquad 4$$
$$C_w(l,t) = 0 \text{ for } 0 < t < \infty \qquad 5$$
$$C_w(y,0) = \varphi \text{ for } 0 < y < l \qquad 6$$

where, l is the thickness of the yam slab and φ is the initial moisture content which is given by

$$\varphi = \frac{w_1 - w_e}{w_e} \qquad 7$$

where, w_1 is the initial mass of the yam slab.
Equation 2 is solved with the boundary conditions of Eqs (4, 5 and 6) to yield

$$w = w_e + \frac{4}{\pi}(w_1 - w_e)\left[e^{-Dt\left(\frac{\pi}{l}\right)^2} - \frac{1}{3}e^{-9Dt\left(\frac{\pi}{l}\right)^2} + \frac{1}{5}e^{-25Dt\left(\frac{\pi}{l}\right)^2} - \frac{1}{7}e^{-49Dt\left(\frac{\pi}{l}\right)^2} \dots\right] \qquad 8$$

Taking the first 4 terms and writing equation (8) in terms of wet moisture content (ϑ) where,

$$\vartheta = \frac{w_1 - w_e}{w_1} \qquad 9$$

$$w = w_1(1-\vartheta) + \frac{4}{\pi}w_1\vartheta\left[e^{-Dt\left(\frac{\pi}{l}\right)^2} - \frac{1}{3}e^{-9Dt\left(\frac{\pi}{l}\right)^2} + \frac{1}{5}e^{-25Dt\left(\frac{\pi}{l}\right)^2} - \frac{1}{7}e^{-49Dt\left(\frac{\pi}{l}\right)^2}\right] \qquad 10$$

Equation (10) is the model equation describing the microwave drying of yam slab.

III. RESULTS AND DISCUSSION

Table 1 shows the comparison of the experimental data to the model results as described by equation (10). Table 1 shows a representative result of 10 yam slabs of 1 cm thickness with which the model results were compared with.

Table 1. **Comparison of experimental data and model result**

Time (mins)	*Experiment mass (g)*	*Model mass (g)*	*% Deviation*
0	9.8470	9.3435	-5.113
2	7.6000	7.5192	-1.063
4	5.7130	5.4808	-4.064
6	4.1960	4.4562	6.200
8	3.8980	3.9425	1.140
10	3.6000	3.6849	2.359
12	3.4370	3.5558	3.457
14	3.4260	3.4911	1.899
Effective Diffusivity		5.83×10^{-8} m^2/s	
Wet Moisture Content		0.6521	

% deviation = (model – experiment)/experiment

It was observed during the experiment that at the 16th minute all yam slabs were burned and therefore any loss in weight after the 14th minute was attributed to burning. Maximum % deviation is 6.2%. The deviation can be attributed to the assumptions made and random error during the experiment. The effective diffusivity of water molecules from the yam at medium low power conditions of the microwave was calculated to be $5.83 \times 10^{-8} m^2/s$ and the wet moisture content of the yam is 0.6521.

Figure 1 shows the graphical representation of the experimental data and the model results. From Figure 1 it is seen that the model accurately predicts the experimental data. This indicates that the model developed is very accurate.

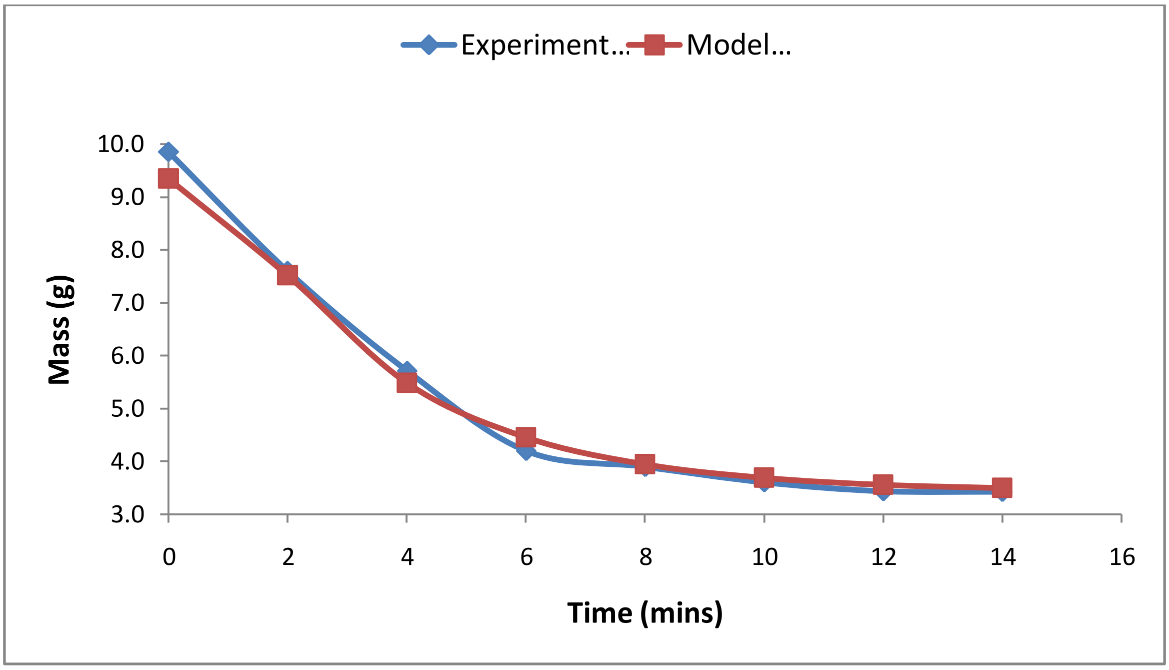

Figure 1. Graph of mass of yam slab against drying time.

The result of the simulation of the model for different thickness of the yam slabs assuming constant initial weight of 9.847g and moisture content of o.6521 is shown in Figure 2. From Figure 2 it can be observed that as the thickness increases, the rate of decrease of the mass (drying) of the yam slab with drying time decreases.

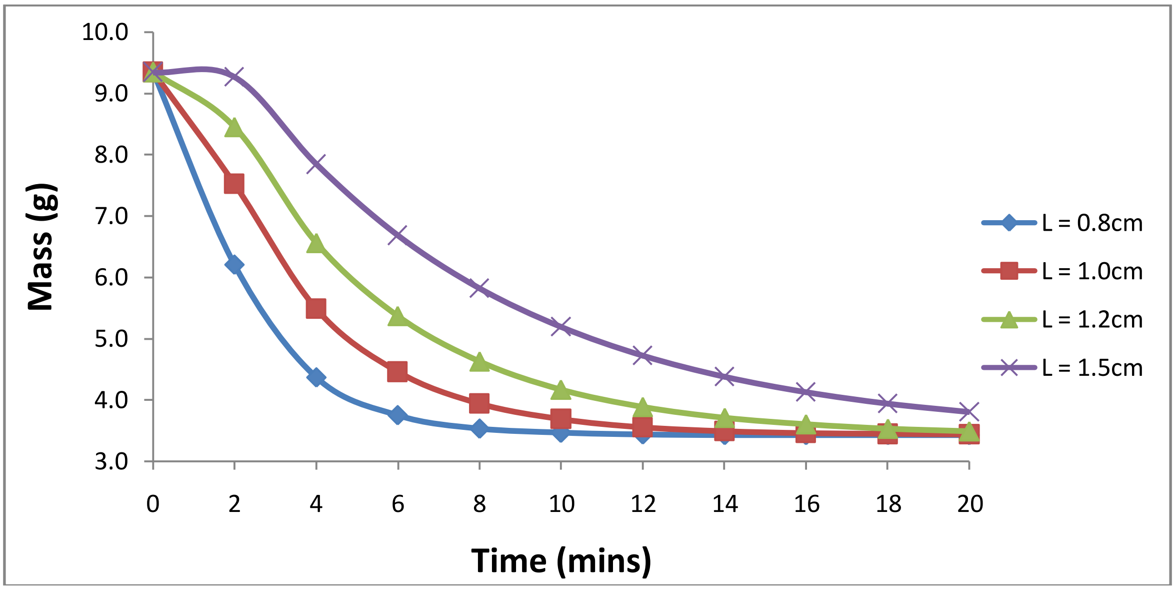

Figure 2. Graph of mass of yam slab against time for different thickness.

This can be attributed to the increase in the distance travelled by the water molecules from the interior of the yam before it is expelled and the corresponding lesser surface (cross section) area available for transfer of water molecules from the yam slab since its initial mass is constant. This indicates that for microwave drying of yam, a thinner thickness of the yam makes for rapid drying of the yam (lesser time for complete drying).
The result of the simulation of the model for different wet moisture content of the yam slabs assuming constant initial weight of 9.847g and thickness of 1cm is shown in Figure 3.

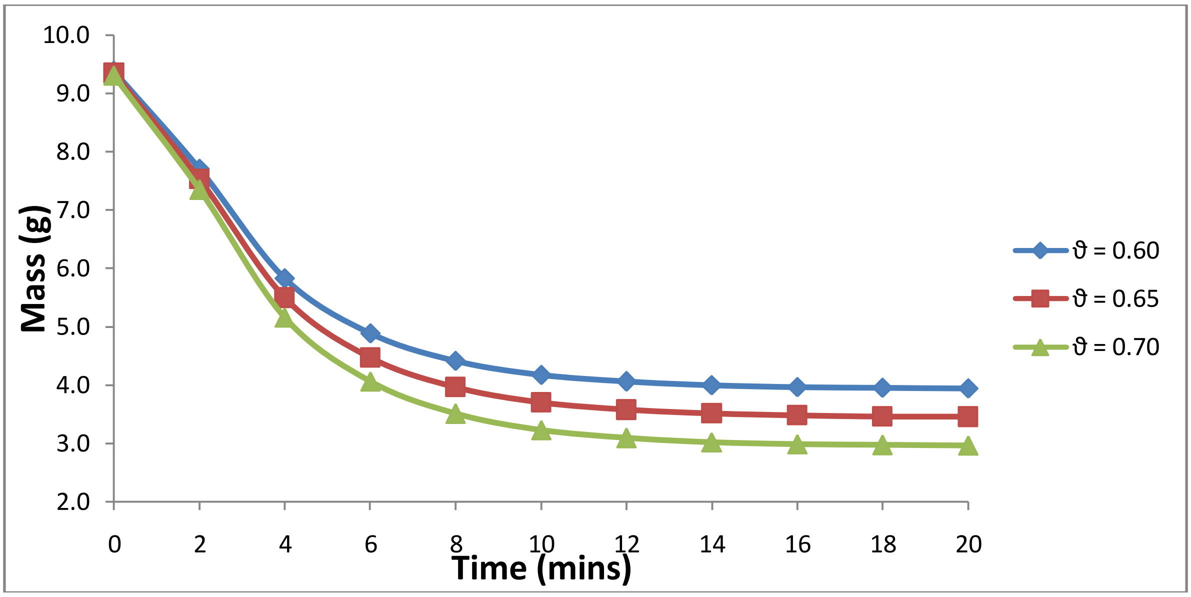

Figure 3. Graph of mass of yam slab against drying time for different wet moisture content.

From Figure 3, it is observed that as the wet moisture content increases the mass of the yam slab when drying is complete decreases. However the mass of yam slab tends to this limiting value following the same trend. This can be attributed to the nature of microwave. The microwave agitates the water molecules inside the yam to produce the heat which drives the drying process from within the yam. The more the water content of the yam, the more water molecules are agitated and as such the rate of removal of water increases. This indicates that for microwave drying of yam, the rate of drying of the yam increases with the water content of the yam and as such the time required for complete drying of the yam is not changed significantly.
The result of the simulation of the model for different initial mass of the yam slabs assuming constant wet moisture content of 0.6521 and thickness of 1cm is shown in Figure 4. From Figure 4 it is observed that the graphs for the different initial mass follow the same trend.

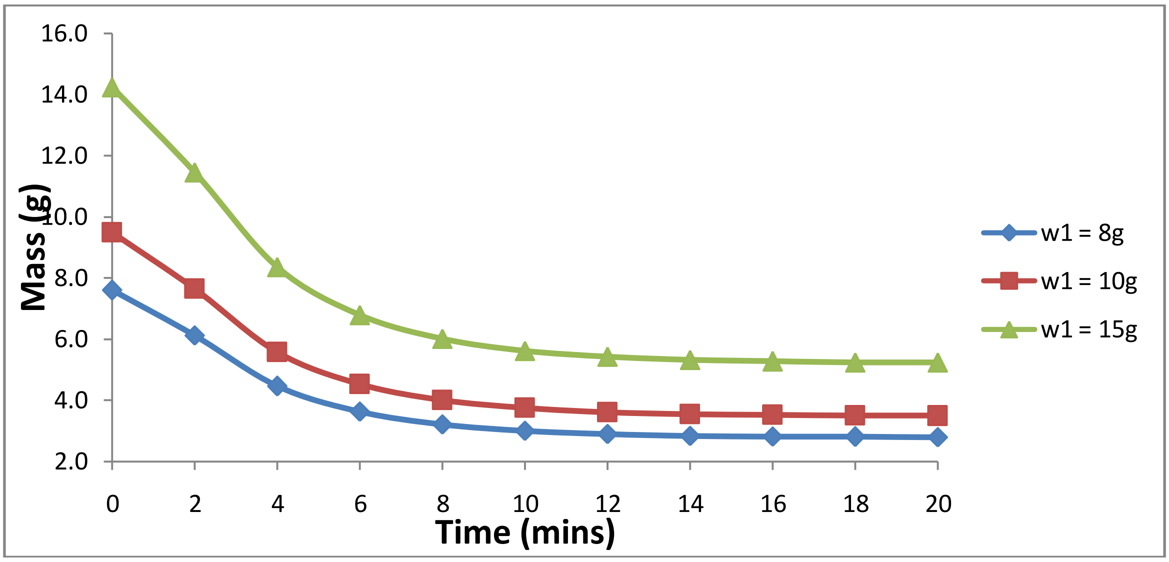

Figure 4. Graph of mass of yam slab against drying time for different initial mass of the yam.

This can be attributed to the corresponding increased area for transfer of water molecules available to the yam slabs of bigger initial mass. This indicates that during the microwave drying of yam, the amount of water expelled per unit area is constant.

IV. CONCLUSION

The reduction in the mass of the yam slab with time at medium low conditions of a microwave oven was investigated. A theoretical model that describes the drying of the yam slab in the microwave was developed and validated using the experimental data. The effective diffusivity of water molecules in yam slab in medium low condition of the microwave oven was calculated to be 5.83 x 10^{-8} m^2/s and the wet moisture content of yam was estimated to be about 65%. Simulations of the model reveals that for microwave drying of yam slabs, the time for complete drying of the yam is independent of the moisture content of the yam and the initial mass of the yam slab but is very sensitive to the thickness of the yam slab. As the thickness of the yam slab increases the time for complete drying of the yam slab increases. It was also observed that the rate of drying of the yam slab increased as the moisture content of the yam slab increased and that the amount of water expelled per unit area of a uniform yam slab is constant during microwave drying.

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