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Mathematical Modeling of Thin Layer Drying of Onion Slices

Garba, K.A., *Kolo, A.S., Yaumi, A.L. and Girei, A.S.

Department of Chemical Engineering, Faculty of Engineering, University of Maiduguri, PMB 1069, Maiduguri, Borno State, Nigeria.
*askolo@unimaid.edu.ng

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ABSTRACT

Onions play significant role in preparing meals and are known to have great medicinal values. An important operation normally deployed in preserving this important vegetable is drying. Dried onions can come in a variety of state which includes flaked, powdered, minced or even chopped. Sun drying with its attendant problems sees the need for dryers designed and constructed based on models. Drying using an electric oven was tested on onion (Allium cepa) in this study. The drying experiments were performed at different temperature of 50 ˚C, 60 ˚C and 70 ˚C. Drying characteristics of onion was studied and a model that describes its behavior was determined. A non-linear regression procedure was used to fit four thin layer drying models (Newton, Page, Modified Page 1, and Henderson & Pabis Models). The models were compared with experimental data of onion drying. The adequacy of fit was evaluated using the coefficient of determination (R^2), mean bias error (MBE) and root mean square error (RMSE). The R^2 and RMSE values indicated that the Page model best describe the drying characteristics of onion. It provides a very good theoretical insight for the design of drying equipment needed for the drying of onion slices.

1. INTRODUCTION

Drying is a significant process operation carried out in many process industries before final packaging of products. This process operation involves both the transfer of mass and heat in order to effectively reduce the moisture content of desired products (Afolabi *et al.*, 2014)

Onions are important vegetables used world-wide in meals and are highly ranked because of their medicinal value (Griffiths *et al.*, 2002). It is the most re-occurring spice in all cooking activities in households. Despite its significance, onions if not properly preserved are susceptible spoilage. One of the locally used method of preserving this important agricultural commodity is drying. Dried onions are a product of considerable importance in world trade and are made in several forms: flaked, minced, chopped, and powdered (Arslan and Ozcan, 2010).

Onions, just like other agricultural products that are sun-dried are susceptible to contamination and other associated problems attributed to sun drying (Ojo *et al.*, 2015). The alternative is the use of dryers which are designed and operated based on mathematical models developed to capture the drying characteristics of these agricultural products (Castro *et al.*, 2018). The technical literature is awash with research undertakings that consider the drying characteristics of many agricultural products while deploying thin layer drying models. Akpinar *et al.* (2003) investigated the thin layer drying of pepper. In their studies, the drying behavior of red pepper slices in a convective dryer was ascertained and thin layer drying models were used. Thin drying models were also used in the study that investigated the drying of eggplants (Ertekin and Yaldiz, 2004). Findings from their studies show the effect of drying air temperature and velocity on drying constant and coefficient. Investigation into the thin layer drying models of Nigerian popcorn varieties was reported by Ademiluyi *et al.* (2008). Popular methodology of fitting drying curves with selected model equations was adopted in their study and model adequacies were analyzed using statistical parameters. Thin layer drying of some fruits and vegetables was studied and findings show that semi-theoretical models describe their drying characteristics (Akpinar, 2006a). In the same vein, Chen *et al.* (2013) reported the mathematical modeling of hot air drying kinetics of *Momordica charantia* slices. These representative review of research findings that employ the use of these empirical, theoretical, and semi-theoretical models suggest the significance and utility of the models in studying the drying behavior of onions. The drying kinetics of ginger slices was also studied using thin layer models (Akpinar and Toraman, 2015)

This research work investigated the drying kinetics of onions using thin layer drying models in order to understand its drying characteristics.

2. MATERIALS AND METHODS

2.1. Raw Materials

Onion was obtained from Gamboru market in Maiduguri Local Government Area of Borno State, Nigeria. Distilled water was prepared in the laboratory.

2.2. Methods

The drying experiments were conducted on fresh onions collected from the local producer. Onion samples were washed with distilled water and cut into slices. The slices weighing about 35.1 g were dried under different conditions of temperature. The drying tests were carried out in an electric oven. To ensure a greater stability of the drying conditions and a perfect homogenization of the temperature inside the oven, the oven was heated for at least half an hour before introducing the product. The drying of the onion was conducted at temperatures of 50 °C, 60 °C, and 70 °C. The loss of weight was recorded in 10 minutes intervals.

2.3. Mathematical Modeling of Drying Curves

The models used and their equations are presented in Equations (1) to (4). The experimental moisture ratio was evaluated using Equation (5).

Newton model:

$$MR = \exp(-kt) \tag{1}$$

Page model:

$$MR = \exp(-kt^n) \tag{2}$$

Modified Page I model:

$$MR = \exp(-(kt)^n) \quad (3)$$

Henderson and Pabis model:

$$MR = a\exp(-kt) \quad (4)$$

$$MR = \frac{X - X_e}{X_o - X_e} \quad (5)$$

Where X is the moisture content at any time t (kg moisture/kg dry matter), X_0 is the initial moisture content (kg moisture/kg dry matter), Xe is the equilibrium moisture content of the product, MR is the moisture ratio (kg moisture/kg dry matter), and t is the drying time. k, n, and a are model constants.

The drying curves of the onions obtained were fitted with four thin layer models. Non-linear regression analysis was performed using Microsoft Excel (2013). The statistical parameters used for determining the adequacy of fit were evaluated using Equations 6 to 8.

$$R^2 = \frac{\sum_{i=1}^{N}(MR_i - MR_{pre,i}) \cdot \sum_{i=1}^{N}(MR_i - MR_{exp,i})}{\sqrt{\sum_{i=1}^{N}(MR_i - MR_{pre,i})^2 \cdot \sum_{i=1}^{N}(MR_i - MR_{exp,i})^2}} \quad (6)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}\left(MR_{i,pre} - MR_{i,exp}\right)^2}{N}} \quad (7)$$

$$MBE = \frac{1}{N}\sum_{i=1}^{N}(\left(MR_{i,pre} - MR_{i,exp}\right) \quad (8)$$

Where $MR_{exp,i}$ is the ith experimental moisture content, $MR_{pre,i}$ is the ith predicted moisture content, R^2 is the coefficient of determination, RMSE is the root mean square error, MBE is the mean bias error, and N is the number of observations.

3. RESULTS AND DISCUSSION

Moisture ratios were computed from moisture content data obtained in the course of the drying experiment. Fitting of the thin layer drying models was done and the results of the statistical parameters are presented in Table 1. R^2, RMSE, and MBE were used in determining model adequacy. Considering the R^2 value, the page model and the modified page model were seen to adequately describe the drying behavior of the onions. But the additional consideration of the RSME value indicated that the Page model better describes the drying behavior. The R^2 value of page model at 60 °C was 0.99 while the RSME value at that temperature is the lowest (-3517.4) for all the models considered. R^2 value of 0.998 was obtained when Page model was judged to favorably describe the drying characteristics of *Momordica charantia* (bitter melon) slices (Chen *et al.,* 2013). R^2 is the most important statistical criteria considered when choosing the best model that describes drying behavior and the higher the value, the better the fit (Akpinar, 2006b). In addition, the lower the value of RSME the better the goodness of the fit (Akpinar, 2006b).

The fit of the Page model can also be seen in the results presented in Figures 1 to 12. The figures compare the plots of moisture ratios against drying time for all the models at the specified temperatures. Figure 6 shows the experimental plots compare favorably well with that of Page model at 60 °C.

The trend in Figures 1 to 12 show that the moisture ratio decrease with increase in drying time. This is the expected trend for other food materials subjected to similar studies (Afolabi *et al*, 2014). The drying constants k also increase with increase in temperature for all the models considered. It increased from 0.17 to 0.25 for the three models. The drying constants also differ for all the models at different temperatures. Similar observation was reported by Ademiluyi *et al.* (2008). This infers the strong dependence of drying constants on temperature.

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Table 1: Results of non-linear regression analysis

Model	T (°C)	Model parameters	R^2	RMSE	MBE
Newton	50	k= 0.1700	0.1935	0.4438	0.2198
	60	k=0.1976	0.1413	0.2850	0.1078
	70	k=0.2251	-0.0037	0.0238	0.1307
Page	50	k=0.2101; n= 0.8947	0.17768	0.4459	0.2198
	60	k=0.2431; n=0.8953	0.99	-3517.4	1.2×10^{34}
	70	k=0.2582; n =0.9180	0.0114	0.0238	0.1025
Henderson	50	k= 0.1827; a=1.2134	0.1871	0.2750	0.2198
	60	k= 0.2083; a=1.1460	-0.8039	0.2850	0.0539
	70	k= 0.2383; a=1.1504	-0.0157	0.2184	0.1308
Modified Page	50	k=0.2101; n= 0.8947	0.1789	0.4449	0.2198
	60	k=0.2431; n=0.8953	0.99	0.2877	0.1445
	70	k=0.2582; n =0.9180	-0.2407	0.2251	0.1069

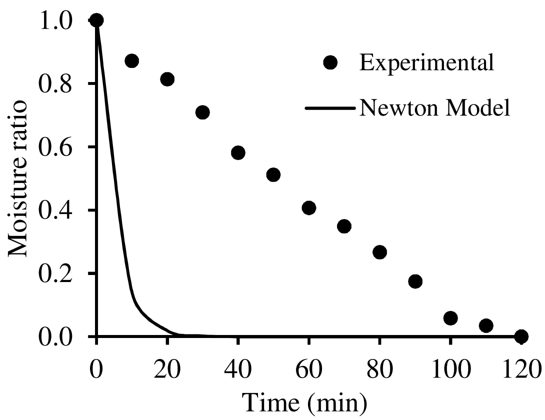

Figure 1: A graph of Newton model and experimental data against time at 50 °C

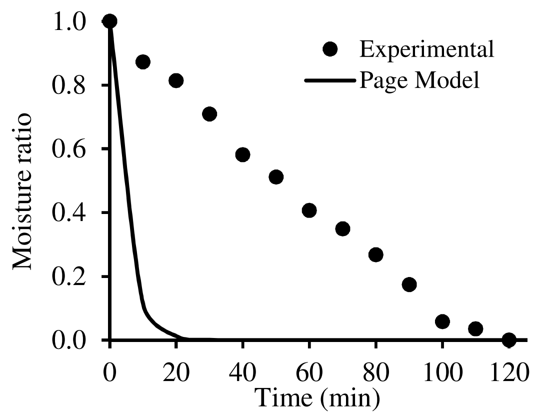

Figure 2: A graph of Page model and experimental data against time at 50 °C

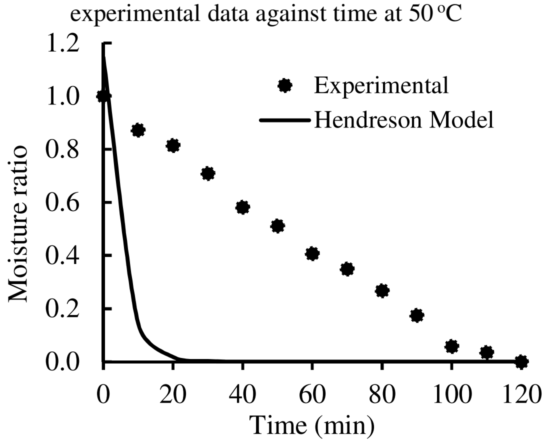

Figure 3: A graph of Henderson model and experimental data against time at 50 °C

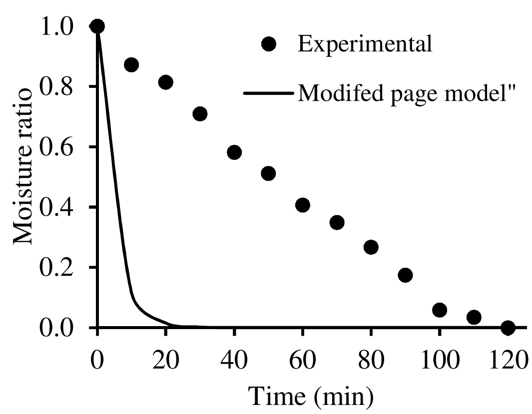

Figure 4: A graph of modified Page model and experimental data against time at 50 °C

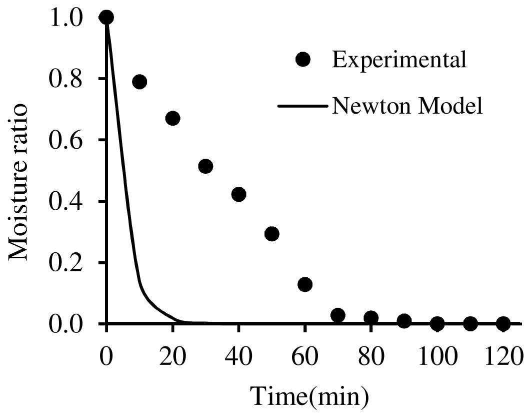

Figure 5: A graph of Newton model and experimental data against time at 60 °C

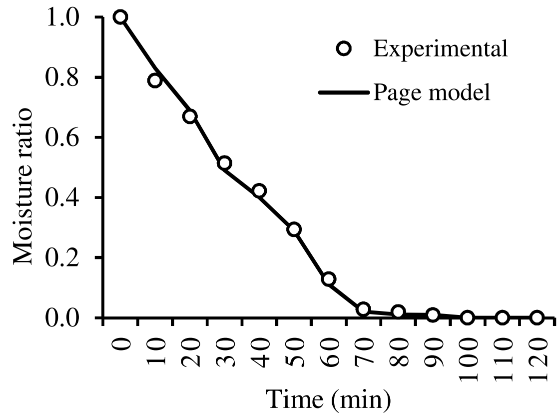

Figure 6: A graph of Page model and experimental data against time at 60 °C

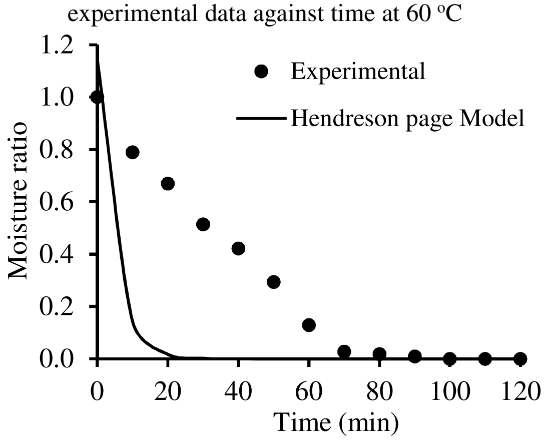

Figure 7: A graph of Henderson model and experimental data against time at 60 °C

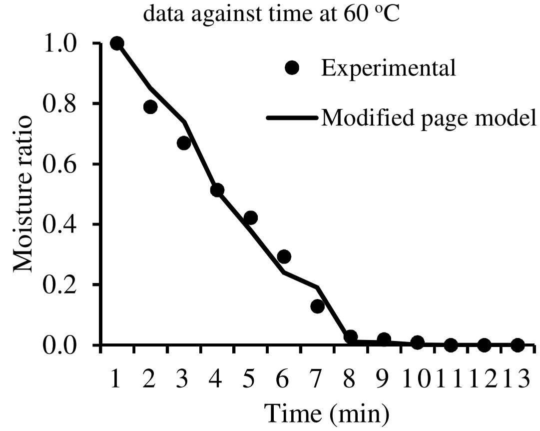

Figure 8: A graph of Modified page and experimental data against time at 60 °C

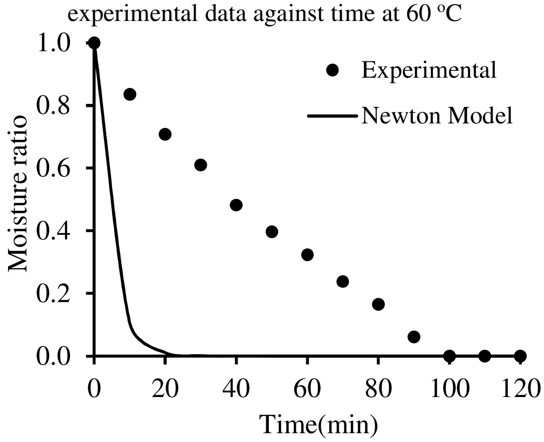

Figure 9: A graph of Newton model and experimental data against time at 70 °C

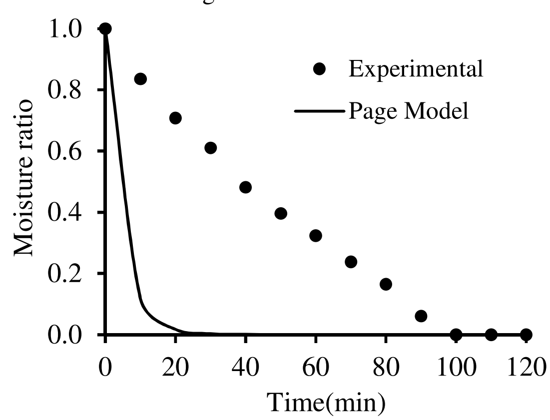

Figure 10: A graph of Page model and experimental data against time at 70 °C

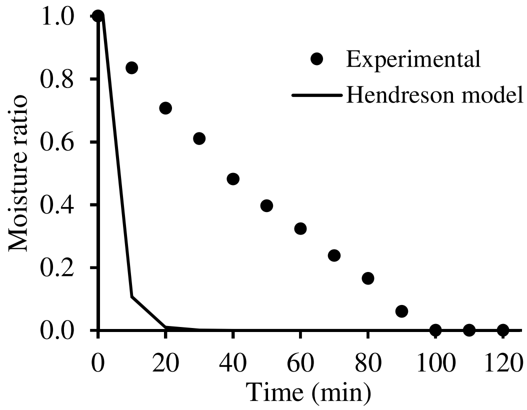

Figure 11: A graph of Henderson model and experimental data against time at 70 ºC

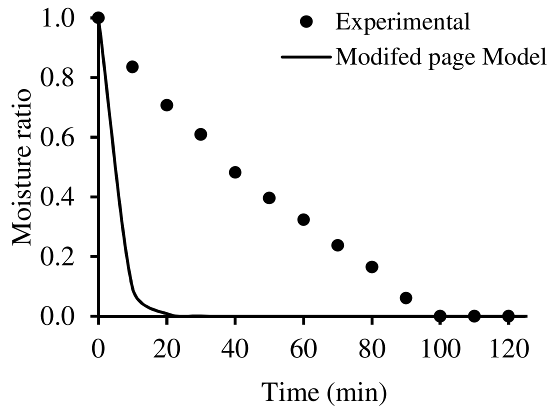

Figure 12: A graph of modified Page model and experimental data against time at 70 ºC

4. CONCLUSION

Experimental moisture contents were exploited in this study alongside drying curve models in order to choose a model that best describes the drying characteristics of onion slices. Results obtained from the methodology adopted indicated that Page model best describes the drying behavior of the slices. These were seen in the statistical criteria deployed in determining model adequacy. The R^2 and RMSE values calculated for the Page model were 0.99 and -3517.4 respectively. Comparing these results and that calculated for the other considered model equations, they satisfied the required conditions necessary to determine adequacy using the parameters. Consequently it was chosen as the model that better describes the drying characteristics of onion slices. This conclusion provides a very good theoretical insight for the design and optimization of drying equipment needed for the drying of onion slices.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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