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DRYING CHARACTERISTICS AND KINETICS OF OKRA AT DIFFERENT THICKNESS

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ABSTRACT

The effect of sample thickness and temperature on the drying characteristics of okra was investigated using a laboratory moisture analyser (Denver instrument IR-30) at sample thickness of 5mm, 10mm and 15mm and temperatures of 90^oC, 100^oC and 110^oC respectively. The experimental data was fitted into three thin layer mathematical models. The fitness of the experimental data were evaluated using statistical analysis. It was observed that data fitted well with the Page model for the temperatures and sample thicknesses with the highest R2 values of (0.9904, 0.9962, 0.9963); (0.9963. 0.0072, 0.9937); (0.9924, 0.9940, 0.9933) for 5mm-. 15mm thickness at 90oC, 100^oC and 110^oC respectively with the lowest χ2, MBE and RMSE values. Therefore, Page models adequately described the drying characteristics of okra investigated. The effective moisture ratios were observed to increase with temperature and decrease with okra thickness. The activation energies obtained from Arrhenius equation for 5mm, 10mm and 15mm were 108.7KJ/mol, 118.7KJ/mol and 97.8KJ/mol respectively.

Contribution/Originality: This study documents the characteristics and kinetics of okra with effect of thickness.

1. INTRODUCTION

Agricultural products such as fresh fruits and vegetables are perishable [1] and difficult to preserve due to their high moisture content and tender texture. This leads to post harvest losses due to deterioration. Also, transportation of such fruits from one place to the other can be cumbersome due to the weight and volume they can occupy. Drying is the most common preservation method for such products [2]. Up till now, a lot of food losses are being experienced due to inadequate preservation, storage and processing techniques

The production of okra in Nigeria is seasonal and often times, the fruits get rotten and become wasted as there are no adequate preservation methods especially at the peak production season where large quantities are produced. Okra is highly nutritious and contains several important micronutrients minerals that the body need [3, 4]. Okra also contains some elements that are essential for the treatment of certain disease conditions in humans [5]. Although the delicacy of okra is in the fresh fruit and it is mostly used fresh to prepare soup, the shelf life is short [4] and cannot be preserved for longer period. Drying of okra is necessary in order to reduce the water content to a reasonable level so as to prevent the growth and production of microorganisms that facilitate deterioration reaction.

Drying will also preserve okra for longer period of time and to make it available and affordable at off season [6]. Furthermore removal of moisture through drying will increase the concentration of the nutrients [7, 8].

Different drying methods have been used to remove moisture from fruits and vegetables in order to preserve the characteristics of the substances. The traditional method of preserving agricultural produce is sun drying where the heat of the sun is utilized to remove the moisture content. Sun drying is slow [9] and the materials can be contaminated with air borne particulates matter [10]. Secondly, during the raining season the sun may not be available so that post-harvest losses are inevitable Also, Sun drying is weather dependent and therefore may not be available at the time of harvest. Again, there may be continuous fluctuation of relative humidity of the drying air during sun drying and the inability to control the drying process [11, 12]. With advancement in technology, microwave drying [13], [14], [15] solar [4] infra-red [3] and hot air drying [16], [17], [18] have been used to dry agricultural products.

Several researchers have studied the drying characteristics of Agricultural products. The quality of products after drying for the purpose of quality assurance, retention of nutrients, color and consumer acceptability have been investigated Ouedraogo, et al. [19]; Md Saleh, et al. [20]. Wankhade, et al. [6] investigated drying of okra slice at different temperatures and observed that the drying rate was increased with temperature. It has also been reported that subjecting okra to different drying methods would affect the final quality of the okra [3, 4, 12, 21]. Cutting okra into different shapes before drying equally affect the drying characteristics of okra [19].

Most of the researchers have investigated the drying characteristics of fruits and vegetables including okra at hot air drying temperatures between 40°C to 70°C but only few have investigated at temperatures up to 100°C [22]. Secondly, only few researchers have investigated the drying characteristics of okra but literature is scarce on the effect okra slice thickness on the effective moisture diffusivity and the kinetics of okra except for Afolabi and Agarry [23] who investigated the effect of sample thickness (10mm and 20mm) on the drying characteristics of okra. Therefore, this study investigates the drying characteristic of okra for three different thicknesses (5mm, 10mm and 15mm) at temperatures 90°C, 100°C and 110°C.

2. MATERIALS AND METHOD

2.1. Materials

Fresh Okra in Figure 1A was obtained from a market in Amassoma, Bayelsa State in Nigeria, stored in a desiccator for two days, and then it was brought out and washed with distilled water. The Okra was sliced in cylindrical shape into three different thicknesses: 5mm, 10mm and 15mm. Example of the sliced okra is presented in Figure 1B.

Figure-1. (A) Shows freshly obtained okra and (B) sliced okra ready for drying.

2.2. Methods

Drying experiments on okra were performed in laboratory scale moisture content analyzer (Denver instrument IR-30) in Chemical Engineering Laboratory at the Niger Delta University, in Chemical Engineering Laboratory at the Niger Delta University, Yenagoa, Nigeria. The IR-30 moisture content analyzer utilizes infrared heating and precision weighing for quick and accurate moisture determination. The dryer basically consists of dark infrared heaters, temperature sensor, exhaust vents, voltage selector, hood exhaust, fuse, power cord receptacle. The drying experiments were carried out at 90ºC, 100ºC and 110ºC. For each temperature, the values of weight loss were taken at 5 minutes interval until constant weight was obtained. From this data, the drying characteristics of okra were investigated.

2.3. Drying characteristics of Okra

The moisture ratio MR of the okra during drying can be determined using Equation 1:

$$MR=\frac{M-M_e}{M_o-M_e} \quad (1)$$

Where M is the mean moisture content, M_o is the initial moisture content and Me is the equilibrium moisture content. The M_e can be neglected since it is very small for food materials compared to M_o and M [24] the Equation 1 is simplified to the ratio of the mean moisture content, M to the initial moisture content of the samples as can be seen in Equation 2.

$$MR=\frac{M}{M_o} \quad (2)$$

The moisture ratio data obtained from Equation 1 was fitted into the three thin layer drying models in Equations 3-5 in order to select the best model that can predict the drying characteristics of okra samples.

1. Newton's Model: $$MR=\frac{M-M_e}{M_o-M_e}=Exp(-kt) \quad (3)$$

2. Page's Model: $$MR=\frac{M-M_e}{M_o-M_e}=Exp(-kt^n) \quad (4)$$

3. Henderson and Pabis Model: $$MR=\frac{M-M_e}{M_o-M_e}=aExp(-kt) \quad (5)$$

Where; M is Moisture ratio at time t, M_e is Equilibrium Moisture ratio, M_o is Initial Moisture ratio. k is slope (for Newton and Henderson's Model), k is Exponential of intercept (For Page Model), n is slope and a is intercept.

Also, Equation 1 is the experimental moisture ratio, (MRexp) while Equations 3-5 are the predicted moisture ratios (MRpre) from the models

2.4. Effective Moisture Diffusivity

Effective Moisture diffusivity was obtained for Okra using Fick's second Law for Diffusion which was simplified to a straight line equation as presented in Equation 6

$$\ln MR = \ln\left(\frac{6}{\pi^2}\right) - \left(\frac{\pi^2 D_{eff}\, t}{r^2}\right) \quad (6)$$

Where D_{eff} is effective moisture diffusivity, t is drying time and r is radius of sample. The effective diffusivities for the samples were determined by plotting ln(MR) vs drying time in Equation 6 to give a straight line with slope (k) as presented in Equation 7.

$$k = \left(\frac{\pi^2 D_{eff}}{r^2}\right) \tag{7}$$

From Equation 7, the D_{eff} of the samples were calculated from the slope, k. Then D_{eff} data obtained was plotted against sample thickness to investigate the relationship between D_{eff} and sample thickness.

2.5. Estimation of Statistical Errors

The fitness of experimental data was evaluated using statistical analysis. The Statistical parameters such as: Mean Bias Error (MBE), Root Mean Square Error (RMSE) and reduced Chi-square error (x^2) were estimated using the following mathematical expressions in Equations 8-10. The x^2 values for all sample thickness at all temperatures for each model was estimated by substituting the MRexp and MRpre into Equation 8. Also, the MBE values were obtained by substituting MRexp and MRpre into Equation 9. Furthermore, the RMSE values were obtained by substituting MRexp and MRpre into Equation 10. The best fit was determined by the coefficient of correlation R^2.

$$\chi^2 = \frac{\sum_{i=1}^{N}(MR_{expi} - MR_{prei})}{N - Z} \tag{8}$$

$$MBE = \frac{1}{N}\sum_{i=1}^{N}(MR_{expi} - MR_{prei}) \tag{9}$$

$$RMSE = \sqrt{\left[\frac{1}{N}\sum_{i=1}^{N}(MR_{expi} - MR_{prei})\right]} \tag{10}$$

Where N is the number of observations, Z is the number of constants, MR_{exp}, is the experimental moisture ratio and $MR_{pre,}$ the predicted moisture ratio

3. RESULTS AND DISCUSSION

3.1. Drying Characteristics

The effect of thickness and temperature on the drying characteristics of okra fruit was investigated by plotting the moisture ratios obtained from Equation 1 (MRexp) against the drying time and the results are presented in Figure 2(a-c). As can been seen in Figure (2a), the drying times for 5mm, 10mm and 15mm okra slices were 70min, 100min and 110min respectively. Increasing the temperature to 100°C reduced the drying times to 60min, 90min and 100mins respectively. Further increase in temperature to 110°C reduced the drying time for 5mm and 10mm and 15mm thick slices to 50min 85min and 101 min respectively. Similar results have also been reported where drying time decreased with increase in drying temperature due to higher moisture reduction at a higher temperature [23]. The results also showed that drying time increased with increase in sample thickness which is similar to results obtained by other researchers [2, 24]. From Figure 2(a-c), it was observed that the drying took place in falling rate period which indicates that the internal heat transfer mechanism is diffusion controlled. Similar falling rate periods have been obtained for drying of green pepper [14] groundnut [18] Scent leave and Bitter leave [10] for okra [3, 24].

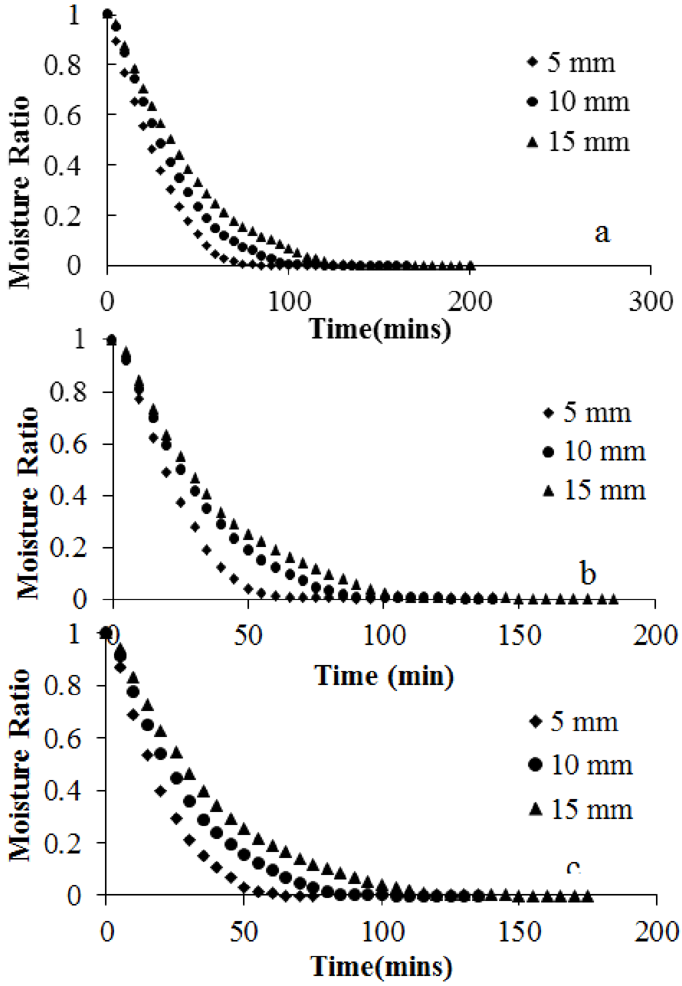

Figure-2. Moisture Ratio vs. Time at temperature (a) 90ºC, (b) 100ºC and (c) 110ºC.

3.2. Choosing a Criteria for Modeling Fitting

The k values, n values and a values obtained from Equation 3-5 for the three models are presented in Tables 1-3. Also, the results of the statistical analysis (χ^2, MBE, RMSE obtained from Equations 8-10 at all temperatures and sample thickness for each model are presented in Tables 1-3. The criteria for choosing the best fit model are the coefficient of correlation R^2, reduced Chi Square (χ^2), Mean biased error (MBE) and the root Mean Square error (RMSE). The results obtained from the statistical analysis showed that the R^2 values of the samples at all temperatures in all the models were more than 0.9, ranged between 0.8202-0.9570 for Newton's model, 0.9904-0.9972 and 0.9360-0.9732 for Page and Henderson and Pabis models respectively. Also, the χ^2, MBE and RMSE values obtained for all temperatures and all thicknesses for the Page model were less than those obtained for Hendersen, Pabis and Newton's models. The χ^2 values for the Newton's model ranged between 0.000986-0.09121 while the values for Page, Henderson and Pabis models ranged between 0.00006-0.000079, and 0.00699-0.11694 respectively. The lower values obtained for Page model indicates that the experimental data fitted well with predicted results using the Page model. The best model chosen in this study was the Page Model which had the highest R^2 value and the lowest (χ^2), MBE and RMSE. The Page model therefore, adequately described the thin layer drying characteristics of okra investigated. Furthermore, the experimental moisture ratio data obtained from Equation 1 were compared with the predicted data for all the temperatures and thicknesses investigated for the page model in Equation 4 and the results presented in Figure 3(a-c). It was observed that the predicted results fitted well with the experimental data for all the temperatures and thicknesses, justifying the fact that the Page model adequately described the drying characteristics of okra slice thickness investigated.

Table-1. Newton's Model constants and estimated error values.

Temperature (°C)	Thickness (mm)	(k)	(R^2)	(MBE)	RMSE)	(χ^2)
	5	0.0603	0.9359	0.01611	0.12693	0.01681
90	10	0.0440	0.9546	0.01217	0.11032	0.01254
	15	0.0354	0.9515	0.01069	0.10338	0.01094
	5	0.0674	0.9553	0.01432	0.11966	0.01503
100	10	0.0472	0.9531	0.00953	0.09761	0.00986
	15	0.0405	0.9570	0.00730	0.08544	0.00748
	5	0.3119	0.8202	0.08585	0.29300	0.09121
110	10	0.2479	0.9043	0.07267	0.26958	0.07527
	15	0.1789	0.9078	0.07098	0.26641	0.07295

Table-2. Page's Model constants and estimated error values.

Temperature (°C)	Thickness (mm)	(k)	(n)	(R^2)	(MBE)	RMSE)	(χ^2)
	5	0.00876	1.4281	0.9904	0.00101	0.03316	0.00119
90	10	0.00538	1.4411	0.9962	0.00008	0.00885	0.00008
	15	0.00460	1.4062	0.9948	0.00014	0.01201	0.00015
	5	0.00698	1.5431	0.9963	0.00006	0.00748	0.00006
100	10	0.00873	1.3711	0.9972	0.00030	0.01733	0.00032
	15	0.00766	1.3661	0.9937	0.00074	0.02729	0.00079
	5	0.01226	1.4499	0.9924	0.00026	0.01603	0.000291
110	10	0.00953	1.3804	0.9940	0.00023	0.01521	0.00025
	15	0.00773	1.3294	0.9933	0.00027	0.01649	0.00029

Table-3. Henderson and Pabis Model constants and estimated error values.

Temperature (°C)	Thickness (mm)	(k)	(a)	(R^2)	(MBE)	(RMSE)	(χ^2)
90	5	-0.0718	2.3731	0.9699	0.10759	0.32800	0.11694
	10	-0.0508	2.0795	0.9781	0.05309	0.23040	0.05630
	15	-0.0408	2.1117	0.9732	0.05279	0.22977	0.05530
100	5	-0.0587	1.0781	0.5954	0.00633	0.07954	0.00699
	10	-0.0547	1.9952	0.9783	0.05047	0.22464	0.05407
	15	-0.0463	2.0318	0.9779	0.04704	0.21688	0.04958
110	5	-0.094	2.2454	0.9360	0.00633	0.07954	0.00699
	10	-0.0653	2.3212	0.9700	0.05047	0.22464	0.05407
	15	-0.0458	2.1550	0.9630	0.04704	0.21688	0.04958

3.3. Relationship between Effective Moisture Diffusivity and Thickness

The relationship between the effective moisture diffusivity and sample thickness was investigated by plotting the effective moisture diffusivity values obtained from Equation 7 against the sample thickness and the results presented in Figure 4. The effective moisture diffusivity was found to be temperature dependent as well as thickness. The values obtained for all temperatures for 5mm thickness was higher compared to what was obtained for 10mm and 15mm. This is due to the fact that sample of smaller thicknesses had larger surface areas; hence the diffusion of water molecules in them took place faster compared to samples of bigger thicknesses. Higher effective moisture diffusivity of materials with smaller thickness have also been observed by other researchers [10].

3.4. Drying Kinetics

The temperature dependency of the effective moisture diffusivity of okra was investigated from Equation 11. Activation energy is the minimum amount of kinetic energy required for a reaction to take place. An increase in temperature brings about a corresponding increase in activation energy. The Deff values obtained from Equation 7 for all samples were inserted into Equation 11.

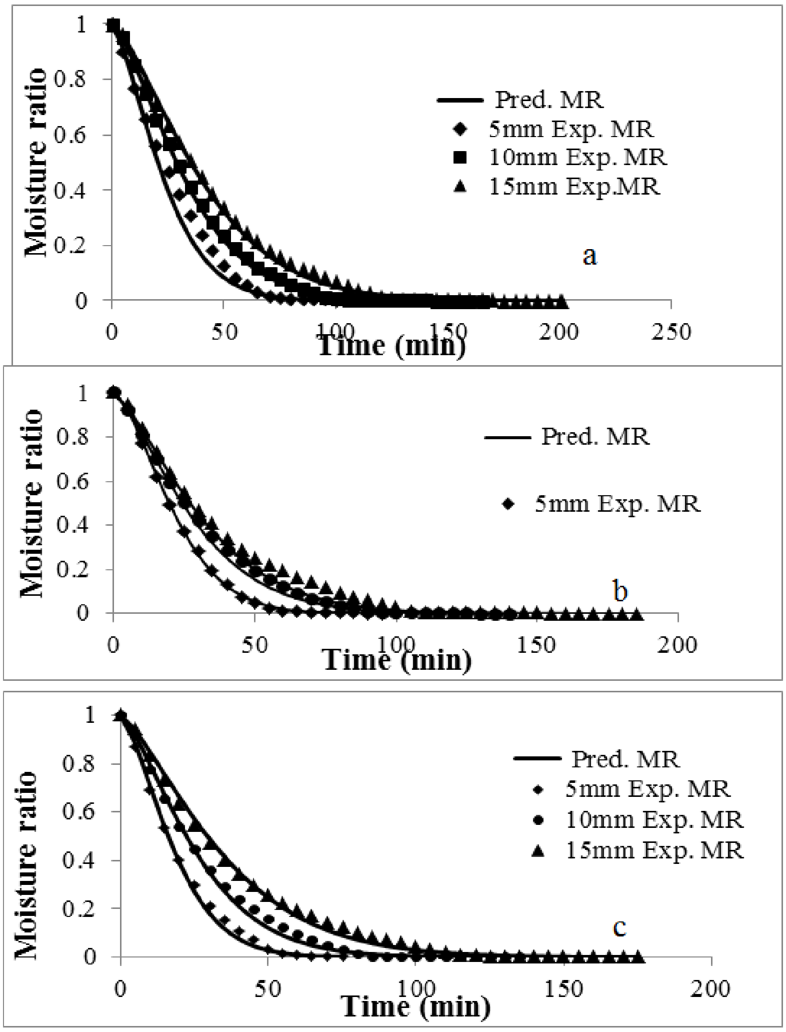

Figure-3. Page's Model for thin layer drying of okra at (a) 90°C, (b) 100°C and (c) 110°C for 5mm, 10mm and 15mm thickness.

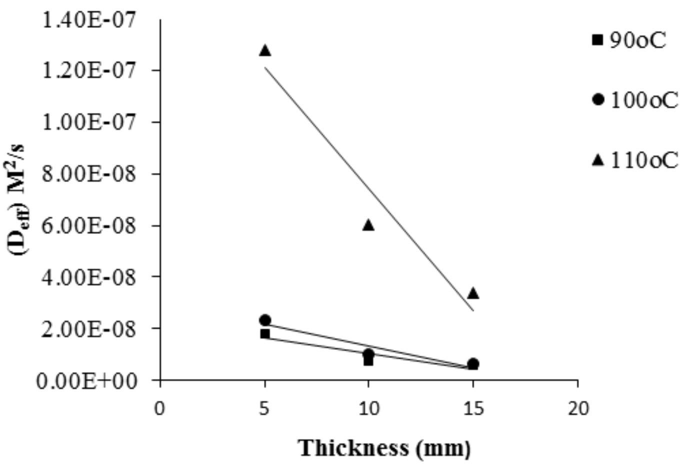

Figure-4. Effective moisture diffusivity versus thickness.

$$D_{eff} = D_o \exp\left(-\frac{Ea}{RT}\right) \quad (11)$$

Where D_o is the pre-exponential factor, Ea is the activation energy, T is the temperature for drying and R is the universal gas constants. From the plot of $\ln(D_{eff})$ against 1/T (Figure 5), activation energy can be obtained from the equation of the line. From the slopes of the straight lines and the intercept in Figure 5, the activation energies and the pre-exponential factors for the different thicknesses were obtained and presented in Table 4.

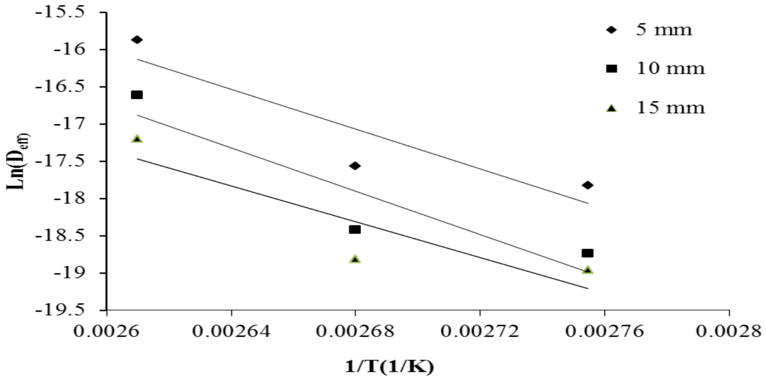

Figure-5. The effect of temperature and effective moisture diffusivity of okra.

Table-4. Kinetic parameters of the showing the dependency of diffusivity coefficient on temperature and thickness during drying.

Thickness	Activation Energy (KJ/mol	Pre-exponential factor
5mm	108.71	1.39×10^8
10mm	118.71	1.43×10^9
15mm	97.75	1.09×10^6

The activation energy for the 5mm sample was 108.7 KJ/mol while for 10mm and 15mm, the values were 118.7KJ/mol and 97.8KJ/mol respectively. These values are higher than values of 43.38KJ/mol obtained by Kumara and Shrivastavaa [15] for green bell pepper, 67.29 KJ/mol by Xiao, et al. [25] for Monukka seedless grapes, 14.97 kJ/mol for okra slice of 10 mm thickness and 10.39 kJ/mol for okra slice of 20 mm thickness by Afolabi and Agarry [23]. However, activation energy value of 110 KJ/mol has also been obtained for drying of scent leave [10].

4. CONCLUSION

The drying characteristics and kinetics of okra has been investigated at thickness of 5mm, 10mm and 15mm at 90°C, 100°C and 110°C. Drying time was observed to decrease with increase in temperature and decrease with increase in sample thickness. The drying time took place at falling rate period hence the drying process was based on diffusion. From the results of the statistical analysis, the experimental data were best predicted by the Page model which gave the lowest values for χ^2, MBE and RMSE to be 0.0006, 0.00006 and 0.00748 respectively and highest R^2 of 0.9972. The effective moisture ratio depended not on the hot air temperature but also on the sample thickness. The activation energies were found also to depend on the sample thickness. The predicted data obtained from Page model could be used for design purposes.

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