Determination of Thin Layer Drying Characteristics of Ginger Rhizome Slices at Varied Temperatures

Gbasouzor Austin Ikechukwu *Member IAENG;* Sabuj Mallik; Dara, Jude Ezechi *Member IAENG*

***Abstract*: This paper is an extension of the previous work done with ARS-680 environmental chamber. Thin layer drying characteristics of ginger rhizomes slices were determined at varied temperature levels ranging from 10°C-60°C and drying time of 2hours – 24hours. Linear and non-linear regression analyses were used to ascertain the relationship between moisture ratio and drying time. Correction analysis, standard error of estimate (SEE) and root mean square error (RMSE) analysis were chosen in selecting the best thin layer drying models. Higher values of determination coefficient (R^2) suggested better confident and lower values of standard error of estimate; and RMSE values were used to determine the goodness of fit. Blanched and unblanched treated ginger rhizomes were considered. The drying data of the variously treated ginger samples were fitted to the twelve thin layer drying models and the data subjects were fitted by multiple non-linear regression technique. Two terms exponential proved to be the model most suitable for predicting the drying characteristics of ginger rhizome.**

Keyword: ***moisture ratio, drying time, thin layer, drying models.***

I. INTRODUCTION

Ginger is the rhizome of the plant *Zingiber officinale*. It is one of the most important and most widely used spices worldwide, consumed whole as a delicacy and medicine. It lends its name to its genus and family *zingiber aceae*. Other notable members of this plant family are turmeric, cardamom, and galangal. Ginger is distributed in tropical and subtropical Asia, Far East Asia and Africa.

Fig. 1 Fresh Ginger Rhyzome/Dried Split Ginger

Ginger is not known to occur in the truly wild state. It is believed to have originated from Southeast Asia, but was under cultivation from ancient times in India as well as in China. There is no definite information on the primary center of domestication.

Because of the easiness with which ginger rhizomes can be transported long distances, it has spread throughout the tropical and subtropical regions in both hemispheres. Ginger is indeed, the most wildly cultivated spice (Lawrence, 1984). India with over 30% of the global share, now leads in the global production of ginger. Nigeria is one of the largest producers and exporters of split-dried ginger (Ravindran et al., 2005).

Convective drying can be employed to remove volatile liquid from porous materials such as food stuffs, ceramic products, clay products, wood and so on. Porous materials have microscopic capillaries and pores which cause a mixture of transfer mechanisms to occur simultaneously when subjected to heating or cooling. The drying of moist porous solids involves simultaneous heat and mass transfer. Moisture is removed by evaporation into an unsaturated gas phase.

Drying is essentially important for preservation of agricultural crops for future use. Crops are preserved by removing enough moisture from them to avoid decay and spoilage. For example, the principle of the drying process of ginger rhizomes involves decreasing the water content of the product to a lower level so that micro-organisms cannot decompose and multiply in the product. The drying process unfortunately can cause the enzymes present in ginger rhizomes to be killed.

The thin layer drying simply means to dry as one layer of sample, particles or slices (Akpinar, 2006). The temperature of thin layers are assumed to be of uniformly distributed and very ideal for lumped parameter models (Erbay and Icier, 2010). Several studies show that thin layer drying equations were found to have wide applications due to their ease of use and less data requirements unlike complex data distributed models (Özdemir and Onur Devres, 1999).

Thin layer drying equations may be expressed in the following models: theoretical, semi-theoretical, and empirical. The theoretical takes into account only the internal resistance to moisture transfer (Parti, 1993) while others are concerned with external resistance to moisture transfer between the product and air (Fortes &Okos, 1980). The theoretical models explain drying behaviors of the product succinctly and can be employed in all process situations. They also include many assumptions causing significant errors. Fick's second law of diffusion are used for the derivation of many of the theoretical models. Semi-theoretical models are also derived from Fick's second law of diffusion and modifications of its simplified forms. They are easier and require fewer assumptions due to use of some experimental data and are valid within the limits of the process conditions applied (Fortes and Okos, 1981).

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II. THEORETICAL REVIEW

Semi-theoretical models

The semi-theoretical models can be classified according to their derivation as:

Newton's law of cooling: includes all models derived from the Newton's law of cooling and are sub-classified into:

a. *Lewis (Newton) model*

This model corresponds to the Newton's law of cooling. Many researchers have named it Newton's model. Lewis (1921) proposed that during the drying of porous hygroscopic materials,

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Materials, the change in moisture content of material in the falling rate period is proportional to the instantaneous difference between the moisture content and the expected moisture content when it comes into equilibrium with drying air. In this proposition, it is assumed that the material is very thin, the air velocity is high and the drying air conditions such as temperature and relative humidity are kept constant.

III. MATHEMATICAL MODELING OF DRYING CURVE

It is expressed mathematically as (Marinos-Kouris and Maroulis, 2006):

$$\frac{dM}{dt} = -K(M - M_e) \qquad (1)$$

Where, K is the drying constant(s^{-1}). In the thin layer drying concept, the drying constant is the combination of drying transport properties such as moisture diffusivity, thermal conductivity, interface heat, and mass coefficients.

If K is independent from M, then Eq.1 can be re-expressed as:

$$MR = \frac{M_t - M_e}{M_i - M_e} = exp(-kt) \qquad (2)$$

Where, k is the drying constant (s^{-1}) obtained from the experimental data in Eq. 2 also known as the Lewis (Newton) model.

Page model and modified forms

Page (1949) further modified Lewis model to obtain an accurate model by introducing a dimensionless empirical constant (n). This modified model in the drying of shelled corns:

$$MR = \frac{(M_t - M_e)}{(M_i - M_e)} = exp(-kt^n) \qquad (3)$$

The following are modified Page models:

i. **Modified Page-I Model:** This form was used to model the drying of soybeans (Overhults et al, 1973). Mathematically expressed in Eq. 4 as:

$$MR = \frac{(M_t - M_e)}{(M_i - M_e)} = exp(-kt)^n \qquad (4)$$

ii. **Modified Page-II Model:** This model was introduced by (White et al., 1976) and is expressed as:

$$MR = \frac{(M_t - M_e)}{(M_i - M_e)} = exp - (kt)^n \qquad (5)$$

iii. **Modified Page equation-II Model:** This model was employed in a study to describe the drying process of sweet potato slices (Diamante and Munro, 1993). It is expressed as:

$$MR = \frac{(M_t - M_e)}{(M_i - M_e)} = exp - (k/l^2)^n \qquad (6)$$

Where l is an empirical dimensionless constant.

Fick's second law of diffusion: the models in this group are derived from Fick's second law of diffusion and are sub-classified into:

a. *Henderson and Pabis (Single term exponential) model and modified forms:*

This is a drying model obtained from Fick's second law of diffusion and applied on drying corns (Henderson and Pabis, 1961). In this model, for long drying times, only the first term (i=1) of the general series solution for the moisture ratio for finite slab can be utilized with negligible error. In Henderson and Pabis (1961) assumption, the analytical solution the moisture ratio for finite slab can be re-expressed as:

$$MR = \frac{(M_t - M_e)}{(M_i - M_e)} = A_1 exp\left(-\frac{\pi^2 D_{eff}}{A_2} t\right) \qquad (7)$$

Where D_{eff} is the effective diffusivity (m^2/s).

If D_{eff} is constant during drying, then Eq. 7 can be re-arranged by using the drying constant k as:

$$MR = \frac{(M_t - M_e)}{(M_i - M_e)} = a\ exp(-kt) \qquad (8)$$

Where a is defined as the indication of shape and generally named as model constant from experimental data. Eq.8 is generally known as the Henderson and Pabis model.

Other forms of Henderson and Pabis models includes:

b. *Logarithmic (Asymptotic) model*

A new logarithmic model of the Henderson and Pabis was proposed by (Chandra and Singh, 1995) and was applied in the drying of laurel leaves (Yagcioglu et al., 1999). This is expressed mathematically as:

$$MR = \frac{(M_t - M_e)}{(M_i - M_e)} = a\ exp(-kt) + c \qquad (9)$$

Where c is an empirical dimensionless constant

c. *Two-Term Model*

Henderson (1974) proposed to use the first two term of the general series solution of Ficks second law of diffusion Eq. (10) for correcting the shortcomings of the Henderson and Pabis model. This model was applied in the drying of grain (Glenn, 1978). The model is expressed as:

$$MR = \frac{(M_t - M_e)}{(M_i - M_e)} = a \exp(-k_1 t) + b\ exp(-k_2 t) \qquad (10)$$

Where a, b are defined as the indication of shape and generally named as model constants and k_1, k_2 are the drying constants (s^{-1}). These constants are obtained from experimental data and equation (10) is referred as Two-Term Model.

d. *Two-Term Exponential Model*

Sharaf-Eldeen et al. (1980) re-expressed the Two-Term Model by cutting down the constant number and organizing the second exponential term's indication of shape constant (b). They stressed that the (b) in the Two-Term Model in

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Eq. (10) should be $(1-a)$ at $t=0$ to get $MR=1$ and proposed a modification as:

$$MR = \frac{(M_t - M_e)}{(M_i - M_e)} = a\exp(-kt) + (1-a)\,exp(-kat) \quad (11)$$

Eq. (11) is called the Two-Term Exponential model

e. *Wang and Singh Model*

Wang and Singh (1978) created a model for intermittent drying of rough rice.

$$MR = 1 + at + bt^2 \quad (12)$$

where, b (s^{-1}) and a (s^{-2}) were constants obtained from experimental data.

f. *Diffusion Approach Model*

Kaseem (1998) rearranged the Verma model (15) by separating the drying constant term k from g and proposed the renewed form as:

$$MR = aexp(-kt) + (1-a)\exp(-kbt) \quad (13)$$

This modified form is known as the Diffusion Approach model. These two modified models were applied for some products' drying at the same time, and gave the same results as expected (Toğrul and Pehlivan, 2003; Akpinar et al., 2003; Gunhan et al., 2005; Akpinar, 2006; Demir et al., 2007).

g. *The Three Term Exponential Models (Modified Henderson and Pabis)*

Henderson and Pabis model and the Two-Term Exponential model were improved by adding the third term of the general series solution of Fick's second law of diffusion Eq. (10) with the view of amending any defect in the models. Karathanos (1999) stressed that the first term, second term and third term highlighted in details the last, the middle and the initial parts of the drying curve $(MR - t)$ as:

$$MR = \frac{(M_t - M_e)}{(M_i - M_e)} = a\exp(-kt) + b\,exp(-gt) + cexp(-ht) \quad (14)$$

Where, $a, b, and\ c$ indicates the dimensionless shape constants and $k, g\ and\ h$ are the drying constants (s^{-1}). Equation (14) is referred to as the Modified Henderson and Pabis model.

h. *Modified Two-Term Exponential Models (Verma et al model)*

Verma et al. (1985) in their study modified the second exponential term of the Two-term Exponential model by adding an empirical constant and used it in the drying of rice. The model modified is referred to as the Verma model and expressed mathematically as:

$$MR = \frac{(M_t - M_e)}{(M_i - M_e)} = a\exp(-kt) + (1-a)exp(-gt) \quad (15)$$

i. *Midilli et al Model*

Midilli et al (2002) modified the Henderson and Pabis by adding extra empirical term that includes t. The model combined the exponential term with a linear term. It was applied to the drying of yellow dent maize and it is expressed as:

$$MR = a.\exp(-kt^n) + bt \quad (16)$$

Developed models from existing models

From Equation (3), the following equations were obtained for exponent, n and drying constant, k respectively

$$n = \frac{(M_e - M_t)}{(M_e - M_i)kt} \quad (17)$$

$$k = \frac{(M_e - M_t)}{(M_e - M_i)n} \quad (18)$$

IV DETERMINATION OF THE MOST SUITABLE MODEL FOR DRYING

Thin layer drying always require a good understanding of the regression and correlation analysis. Linear and non-linear regression analyses are used to ascertain the relationship between moisture ratio and drying time in thin layer drying for selected drying models. The recommended models chosen for applications were further validated using correlation analysis, standard error of estimate (SEE) and root mean square error (RMSE) analysis respectively. The major indicator for selecting the best models is the determination coefficient (R^2). The higher values of determination coefficient and lower values of standard error of estimate and RMSE are used to determine the goodness of fit (Akpinar, 2006; Erbay & Icier, 2010; Verma et al., 1985). The determination coefficient (R^2); standard error of estimate (SEE) and root mean square error (RMSE) calculations can be performed using the following Eqs 19, 20 and 21 respectively.

$$R^2 = \frac{\sum_{i=1}^{N}(MR_i - MR_{pre,i})\sum_{i=1}^{N}(MR_i - MR_{exp,i})}{\sqrt{\left[\sum_{i=1}^{N}(MR_i - MR_{pre,,i})^2\right] - \left[\sum_{i=1}^{N}(MR_i - MR_{exp,i})^2\right]}} \quad (19)$$

$$SEE = \frac{\sum_{i=1}^{N}(MR_{exp,i} - MR_{pre,i})^2}{d_f} \quad (20)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i})^2\right]^{1/2} \quad (21)$$

Where N is the number of observations, $MR_{pre,i}$ ith predicted moisture ratio values, $MR_{exp,i}$ ith experimental moisture ratio values, and $d_f$is the number of degree of freedom of regression model.

V. STATISTICAL VALIDATION OF THE DRYING MODEL

Both theoretical considerations and experimental investigations of drying processes are focused on the drying kinetics. The drying kinetics includes changes in moisture content and changes in mean temperature with respect to drying time. Drying studies provide the basis for understanding the unique drying characteristics of any particular food material. In the study of drying process, the moisture content of bio material exposed to a stream of drying air is monitored over a period of time.

Drying models are used for the investigation of the drying kinetics (Ceylan et al., 2007). A number of mathematical models have been developed to simulate moisture movement and mass transfer during the drying of many agricultural products. In this work, the experimental moisture ratio data of the various ginger treatments were fitted to twelve drying models. (Eqs 2, 3, 5, 8-16) and the summary is given in table 1.

The drying data of the ginger samples were fitted to the twelve thin layer drying models and the data subsets were fitted by multiple non-linear regression technique. Regression analyses were performed using the R Project for Statistical Computing (R version 3.5.2).The determination coefficient, (R^2), is the primary basis for selecting the best equation to describe the drying curve. The models with the highest values of R^2 are the most suitable models for describing the thin layer drying characteristics of the ginger samples. Besides R^2, the standard error of estimate (SEE) and root mean square error (RMSE) were used to determine the goodness of fit. The values of SEE and RMSE should be low for good fit. Tables 2-3 presented the results of the curve fitting computations with the drying time for the twelve models with statistical analysis.

Table 1: Drying Models for Agricultural Products

S/N	Model Name	Drying Model
1	Newton	$MR = \exp\,(-kt)$
2	Page	$MR = \exp\,(-kt^n)$
3	Modified Page	$MR = \exp\ -(kt)^n$
4	Henderson and Pabis	$MR = a.\exp\,(-kt)$
5	Logarithmic	$MR = a.\exp(-kt) + c$
6	Two term	$MR = a.\exp(-k_o t) + b.\exp\,(-k_1 t)$
7	Two term exponential	$MR = a.\exp(-kt) + (1-a)\exp\,(-kat)$
8	Wang and Singh	$MR = 1 + \mathrm{at} + \mathrm{bt}^2$
9	Diffusion approach	$MR = a.\exp(-kt) + (1-a)\exp\,(-kbt)$
10	Modified Henderson and Pabis	$MR = a.\exp(-kt) + b.\exp(-gt) + c.\exp\,(-ht)$
11	Verma et al.	$MR = a.\exp(-kt) + (1-a)\exp\,(-gt)$
12	Midilli et al.	$MR = a.\exp(-kt^n) + bt$

Table 2: Coefficient of models and goodness of fit for Unblanched ginger

S/N	Model	Temp	Parameter	R-Square	RMSE	SEE
1	Newton	10	k= -0.1738	0.4557	64.3219	0.0437
		20	k= -0.1723	0.4562	59.8300	0.0422
		30	k= -0.1663	0.4405	60.7943	0.0494
		40	k= -0.1564	0.4307	48.3551	0.0496
		50	k= -0.1399	0.4035	40.8199	0.0616
		60	k= -0.1171	0.3624	39.1357	0.1006
2	Page	10	k= -4.7054, n= -0.0491	0.7746	6.6736	0.1182
		20	k= -4.6631, n= -0.0525	0.8475	5.1806	0.0975
		30	k= -4.7522, n= -0.0649	0.7382	8.8685	0.1657
		40	k= -4.6913, n= -0.0889	0.9559	3.3324	0.0763
		50	k= -4.7001, n= -0.1220	0.9412	4.1183	0.1139
		60	k= -4.8946, n= -0.1692	0.8743	7.4558	0.2314
3	Modified Page	10	k= -2110000, n= 0.0832	0.2677	30.7637	39900000
		20	k= -2141000, n= 0.0822	0.2628	28.5385	40790000
		30	k= -4409000, n= 0.0784	0.2132	31.6093	104800000
		40	k= k= -3496000, n=0.0763	0.1725	26.3335	90820000
		50	k= -6722000, n= 0.0993	0.1199	24.6464	243400000
		60	k= -0.00008, n= -0.1693	0.8743	7.4558	0.0313
4	Henderson and Pabis	10	k= 0.0299, a= 95.8216	0.9345	3.7042	3.8099
		20	k= 0.0303, a= 89.9556	0.9310	3.6031	3.7144
		30	k= 0.0409, a= 97.2675	0.9139	5.2717	5.7999
		40	k= 0.0506, a= 83.5059	0.9588	3.4020	3.9632
		50	k= 0.0722, a= 79.7556	0.9867	2.0894	2.7490
		60	k= 0.1077, a= 89.5462	0.9792	3.1820	5.0421
5	Logarithmic	10	k= 0.0297, a= 96.2870, c= -0.4886	0.9345	3.7041	171.5739
		20	k= 0.0566, a= 63.6015, c= 29.1920	0.9380	3.3824	44.7031
		30	k= 0.0374, a= 102.5839, c= -5.7667	0.9144	5.2667	155.2513
		40	k= 0.1155, a= 66.0792, c= 26.4788	0.9911	1.5304	6.6286
		50	k= 0.1121, a= 72.1372 c= 13.3545	0.9990	0.5569	2.4776
		60	k= 0.0997, a= 90.9417, c= -2.6588	0.9800	3.1412	15.9152
6	Two Term	10	K1= 0.0328, k2= 0.4860, a= 100.12 , b= -14.18	0.9408	3.5478	67.3540
		20	k1= -0.1975, k2= 0.0359, a= 0.0652, b= 92.50	0.9494	3.0662	8.6839
		30	k1= 0.0484, k2= 0.4031, a= 108.48, b= -27.04	0.9281	4.8917	84.5508
		40	k1= 0.0172, k2= 0.1602 , a= 44.07 , b= 50.50	0.9916	1.4888	68.4724
		50	k1= 0.0386, k2= 0.1812, a= 43.44, b= 44.82	0.9994	0.4129	25.9763
		60	k1= 0.0101, k2= 4.353, a= 83.38, b= 36130	0.9824	2.9025	394605484
7	Two Term Exponential	10	k= 0.0300, a= 95.93	0.9349	3.6865	3.6564

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		20	k= 0.0306, a= 90.2740	0.9307	3.6283	3.5850
		30	k= 0.0409, a= 97.2743	0.9138	5.2696	5.7670
		40	k= 0.0505, a= 83.53	0.9588	3.4048	3.9541
		50	k= 0.07221, a= 79.75	0.9867	2.0896	2.7486
		60	k= 0.1077, a= 89.5462	0.9792	3.1820	5.0421
8	Wang and Singh	10	a= 12.4486, b= -0.4665	0.3867	32.7700	3.85
		20	a= 11.4252, b= -0.4242	0.3676	31.5500	3.71
		30	a=11.6757, b= -0.4523	0.3623	33.4244	3.9258
		40	a= 8.8782, b= -0.3432	0.3113	29.5096	3.4660
		50	a= 7.3172, b= -0.2974	0.2963	27.0252	3.1742
		60	a= 6.6709, b= -0.2924	0.2939	28.3493	3.3297
9	Diffusion Approach	10	k= 0.1600, a= 195300, b= 1.001	0.6767	16.2880	11510000000
		20	k= 0.1612, a= 191300, b= 1.001	0.6397	16.6644	4285000000
		30	k= 0.1806, a= 72100, b= 1.004	0.7638	14.0258	2017000000
		40	k= 0.200, a= 6468, b= 1.032	0.7066	14.6413	12530070
		50	k= 0.2402, a= 221300, b= 1.001	0.8086	10.8549	10980000000
		60	k= 0.2869, a= 471100, b= 1.00	0.8913	8.4190	4267000000
10	Modified Henderson and Pabis	10	k= -0.5331, a= 0.00003, b= 298.4, g=0.0775, c= -213.5, h= 0.1197	0.9728	2.3789	64638.62
		20	k= -0.0319, a= 285.0, b= 164.1, g= -0.0835, c= -361.9, h= -0.0665	0.9717	2.2788	15457702
		30	k= 0.4411, a= -21.57, b= 301.1, g= 0.0603, c= -196.92, h= 0.0695	0.92665	4.9615	19006351
		40	k= 0.1252, a= 100.1, b= 250.9, g= 0.0415, c= -256.6 , h= 0.0557	0.9916	1.4863	22319738
		50	k= 0.1252, a= 100.1, b= 250.9, g= 0.0415, c= -256.6 , h= 0.0557	0.7720	10.4271	22319738
		60	k= 0.1252, a= 100.1, b= 250.9, g= 0.0415, c= -256.6 , h= 0.0557	0.6302	17.5589	22319738
11	Verma et al.	10	k= 0.0315, a= 97.9646, g= 1.6684	0.9387	3.5989	7.1512
		20	k= 0.0315, a= 97.9646, g= 1.6685	0.8576	6.0239	7.1512
		30	k= 0.0441, a= 101.52, g= 1.4019	0.9209	5.0911	11.1057
		40	k= 0.0441, a= 101.52, g= 1.4019	0.6988	14.4358	11.1057
		50	k= 0.0441, a= 101.52, g= 1.4019	0.5952	24.2886	11.1057
		60	k= 0.0441, a= 101.52, g= 1.4019	0.5574	30.6585	11.1057
12	Midilli et at	10	k= -4.4492, a= -0.2297, b= 1.2110	0.6801	11.7124	1.1793
		20	k= -4.4356, a= -0.2418, b= 1.1722	0.7837	8.5460	0.87393
		30	k= -4.3899, a= -0.2158, b= 0.5625	0.8661	7.8576	0.7985
		40	k= -4.5787, a= -0.3113, b= 0.7594	0.8040	8.6490	0.9213
		50	k= -4.5178, a= -0.3290, b= 0.2430	0.89709	6.2558	0.7030
		60	k= -4.5607, a= -0.3298, b= -0.3387	0.9613	4.5454	0.5032

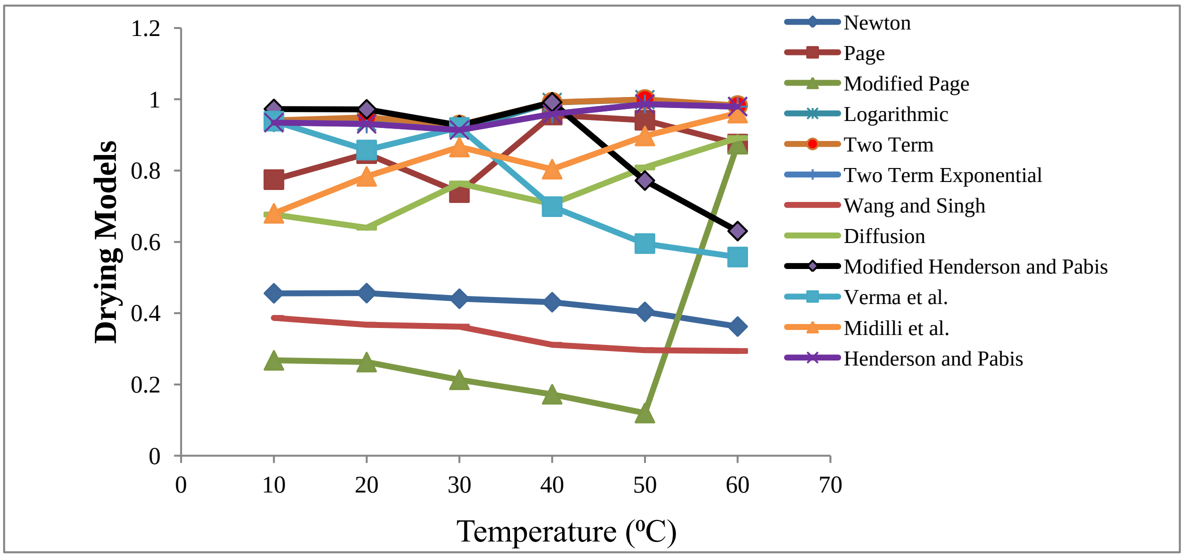

Figure 2 Drying models versus temperature for determination coefficient (Unblanched Treatment)

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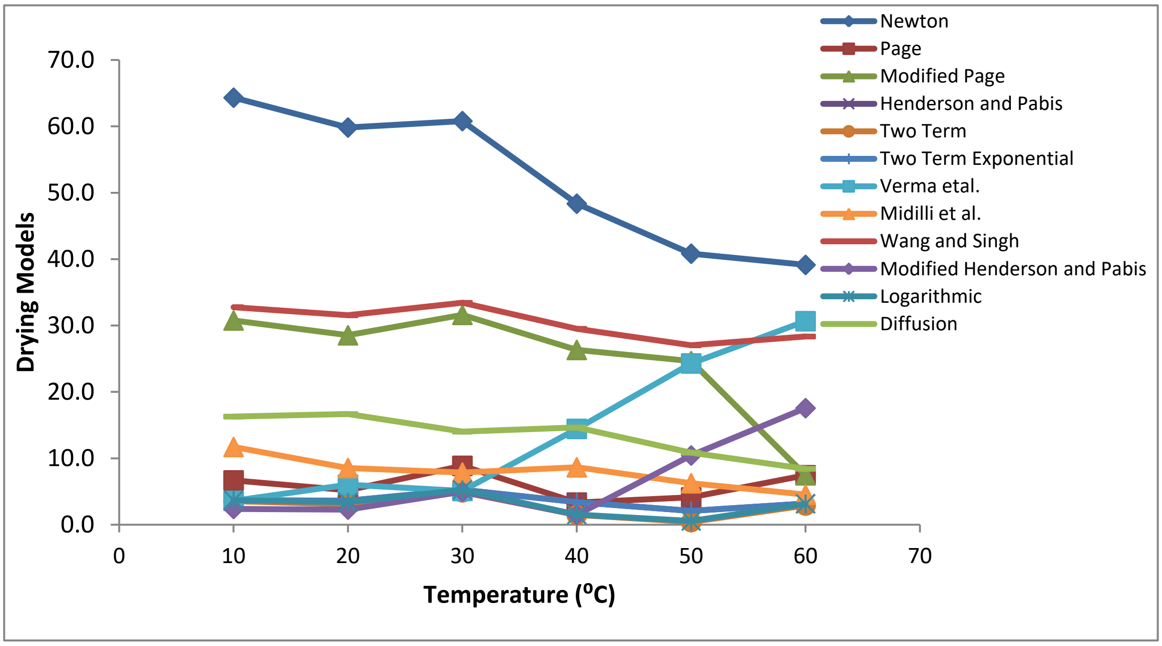

Figure 3 Drying models versus temperature for RMSE (Unblanched Treatment)

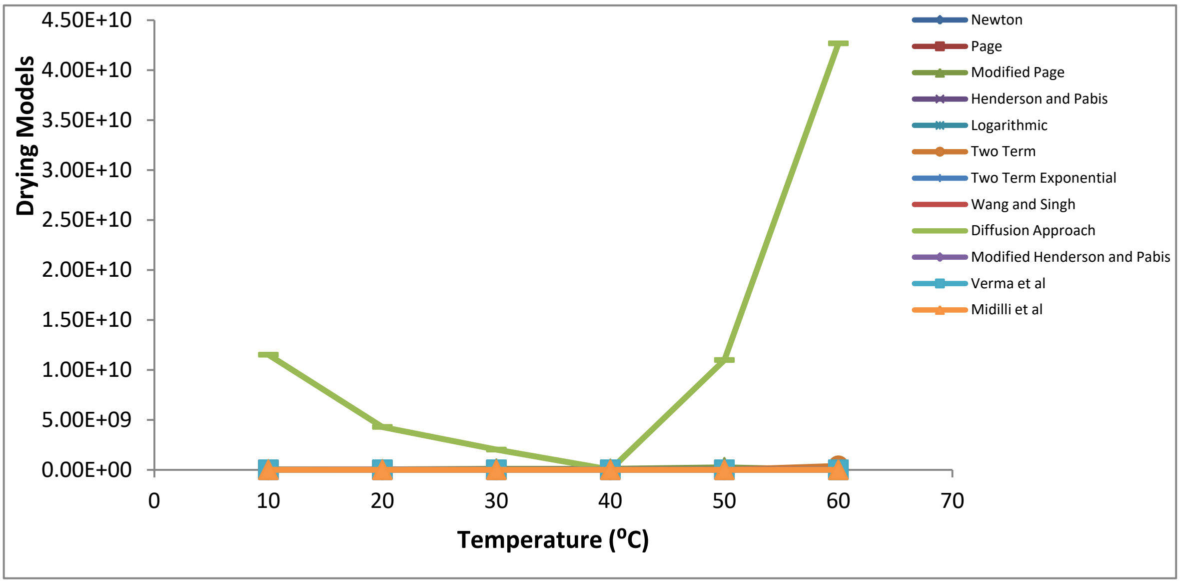

Figure 4 Drying models versus temperature for SEE (Unblanched Treatment)

Figures 2 to 4 were plotted using Table 2. Figure 1 showed that page model can be used to predict the drying characteristics of unblanched ginger treatment at temperature above 40°C. But below 40°C, this model might not be suitable to simulate the drying characteristics of unblanched ginger. Figures 2 to 4 showed that Henderson and Pabis model, Logarithmic model, two term model and two term exponential model can be used to predict the drying characteristics of unblanched ginger treatment; but, two term exponential and Henderson and Pabis are most suitable for the prediction of the drying characteristics of the unblanched ginger rhizome treatment.

Table 3: Coefficient of models and goodness of fit for Blanched ginger

S/N	Model	Temp	Parameter	R-Square	RMSE	SEE
1	Newton	10	k= -0.1675	0.4487	56.9359	0.0449
		20	k= -0.1611	0.4320	56.9113	0.05228
		30	k= -0.1422	0.3983	55.2101	0.0790
		40	k= -0.1352	0.3850	37.7302	0.0636
		50	k= -0.1216	0.3659	36.9169	0.0854
		60	k= -0.1171	0.3624	39.1357	0.1006
2	Page	10	k= -4.6889, n= -0.0633	0.9176	4.1165	0.0808
		20	k= -4.7754, n= -0.0777	0.8124	7.8502	0.1553
		30	k= -4.9152, n= -0.1088	0.71565	12.8780	0.2713
		40	k= -4.7471, n= -0.1448	0.9388	4.4175	0.1342
		50	k= -4.7528, n= -0.1572	0.8127	8.3007	0.2700

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		60	k= -4.8946, n= -0.1692	0.8743	7.4558	0.2313
3	Modified Page	10	k= -4226000, n= 0.0 782	0.2309	28.0725	92440000
		20	k= -3125000, n= 0.0 789	0.1842	31.2239	78310000
		30	k= -588800, n= 0.0738	0.1241	35.3529	220500000
		40	k= -18740000, n= 0.0643	0.0996	24.0806	874700000
		50	k= -9024000, n= 0.0651	0.0874	25.3152	483500000
		60	k= -0.00008, n= -0.1693	0.87432	7.4558	0.0313
4	Henderson and Pabis	10	k= 0.0364, a= 89.3923	0.9745	2.3897	2.5594
		20	k= 95.8828, a= 89.9556	0.9503	4.2258	4.8620
		30	k= 0.0738, a= 105.85	0.9270	6.7505	8.9577
		40	k= 0.0881, a= 80.21	0.9633	3.7128	5.3178
		50	k= 0.0995, a= 81.56	0.9528	4.3866	6.6680
		60	k= 0.1077, a= 89.5462	0.9792	3.1820	
5	Logarithmic	10	k= 0.0746, a= 64.2547, c= 29.8133	0.9890	1.5410	12.2574
		20	k= 0.0571, a= 88.52, c= 8.5958	0.9507	4.1861	54.2203
		30	k= 0.0462, a= 131.86, c= -30.57	0.9401	6.2679	122.0081
		40	k= 0.1498, a= 75.83, c= 13.78	0.9874	2.0737	7.9296
		50	k= 0.0941, a= 82.68, c= -1.8811	0.9536	4.3728	23.9501
		60	k= 0.0997, a= 90.94, c= -2.6588	0.9800	3.1412	15.9152
6	Two Term	10	k1= -0.1352, k2= 0.0441, a= 0.3545, b= 92.0785	0.9902	1.4544	6.3997
		20	k1= 0.0516, k2= 0.4456, a= 100.32, b= -11.46	0.9526	4.1547	79.6655
		30	k1= 0.1260, k2= 0.2279, a= 255.99, b= -179.65	0.9623	5.0445	2635.26
		40	k1= -0.0904, k2= 0.1121, a= 1.2774, b= 84.96	0.9891	1.9295	10.3514
		50	k1= -0.0904, k2= 0.1121, a= 1.2774, b= 84.96	0.9105	5.8401	10.3514
		60	k1= 0.1007, k2= 4.353, a= 83.38, b= 36130	0.9824	2.9025	394605484
7	Two Term Exponential	10	k= 0.0365, a= 89.51	0.9743	2.4011	2.5274
		20	k= 0.0484, a= 95.88	0.9503	4.2256	4.8540
		30	k= 0.0738, a= 105.85	0.9270	6.7505	8.9576
		40	k= 0.0881, a= 80.21	0.9633	3.7128	5.3177
		50	k= 0.0995, a= 81.56	0.9528	4.3866	6.6679
		60	k= 0.1077, a= 89.5462	0.9792	3.1820	5.0421
8	Wang and Singh	10	a= 10.7915, b= -0.4071	0.3520	31.3122	3.6776
		20	a= 10.74, b= -0.4217	0.3406	33.1157	3.8895
		30	a= 10.29, b= -0.4353	0.3428	35.0269	4.1139
		40	a= 6.3126, b= -0.2574	0.2548	27.2138	3.1963
		50	a= 6.2735, b= -0.2702	0.2823	26.7532	3.1422
		60	a= 6.6709, b= -0.2924	0.2939	28.3493	3.3297
9	Diffusion Approach	10	k= 0.2738, a= 286200, b= 1.001	0.6627	16.2673	9949000000
		20	k= 0.1949, a= 75260, b= 1.003	0.7796	3.5730	9504000000
		30	k= 0.0231, a= 101600, b= 1.002	0.9083	9.1213	3442000000
		40	k= 0. 2720, a= 276900, b= 1.001	0.8364	10.1288	4205000000
		50	k= 0.2402, a= 221300, b= 1.001	0.9038	7.2400	4776000000
		60	k= 0.2869, a= 471100, b= 1.00	0.8913	8.4190	4267000000
10	Modified Henderson and Pabis	10	k= -0.1252, a= 100.1, b= 250.9, g=0.0415, c= -256.6, h= 0.0557	0.7502	11.2536	22319738
		20	k= -0.5382, a= 0.00003, b= 297.7, g= 0.1028, c= -214.6, h= 0.1537	0.9818	2.5323	48486.55
		30	k= -0.5382, a= 0.00003, b= 297.7, g= 0.1028, c= -214.6, h= 0.1537	0.7861	10.3395	48486.55
		40	k= -0.5382, a= 0.00003, b= 297.7, g= 0.1028, c= -214.6, h= 0.1537	0.6085	23.7125	48486.55
		50	k= -0.4659, a= 0.00007, b= 171.4, g= 0.1499, c= -105.1, h= 0.2611	0.9671	3.6323	13977.55
		60	k= 0.1367, a= 127.6, b= 4432, g= 1.670, c= -1221 , h= 0.9579	0.9971	1.1897	2665399
11	Verma et al.	10	k= 0.0440, a= 101.52, g= 1.4019	0.9293	4.8420	11.1057
		20	k= 0.0495, a= 97.19, g= 1.98	0.9510	4.2036	10.6059
		30	k= 0.0885, a= 126.07, g= 0.8917	0.9468	5.8809	24.0566
		40	k= 0.0885, a= 126.07, g= 0.8917	0.7114	18.8661	24.0567
		50	k= 0.1004, a= 82.35, g= 2.3186	0.9530	4.3842	19.6168
		60	k= -0.0491, a= 1.00, g= -1.00	0.5001	45221.66	2299.48
12	Midilli et al.	10	k= -4.5065, a= -0.2643, b= 1.0657	0.7582	9.5627	0.9778
		20	k= - 4.4475, a= - 0.2372, b= 0.4568	0.8890	7.2390	0.7340
		30	k= -4.4283, a= -0.2211, b= -0.4783	0.9475	6.2365	0.6280
		40	k= -4.6171, a -0.3675, b= 0.1731	0.9011	6.2294	0.7263
		50	k= - -4.36909, a= -0.3080, b= -0.3485	0.9502	4.6823	0.5370
		60	k= -4.5607, a= -0.3298, b= -0.3387	0.9613	4.5454	0.5032

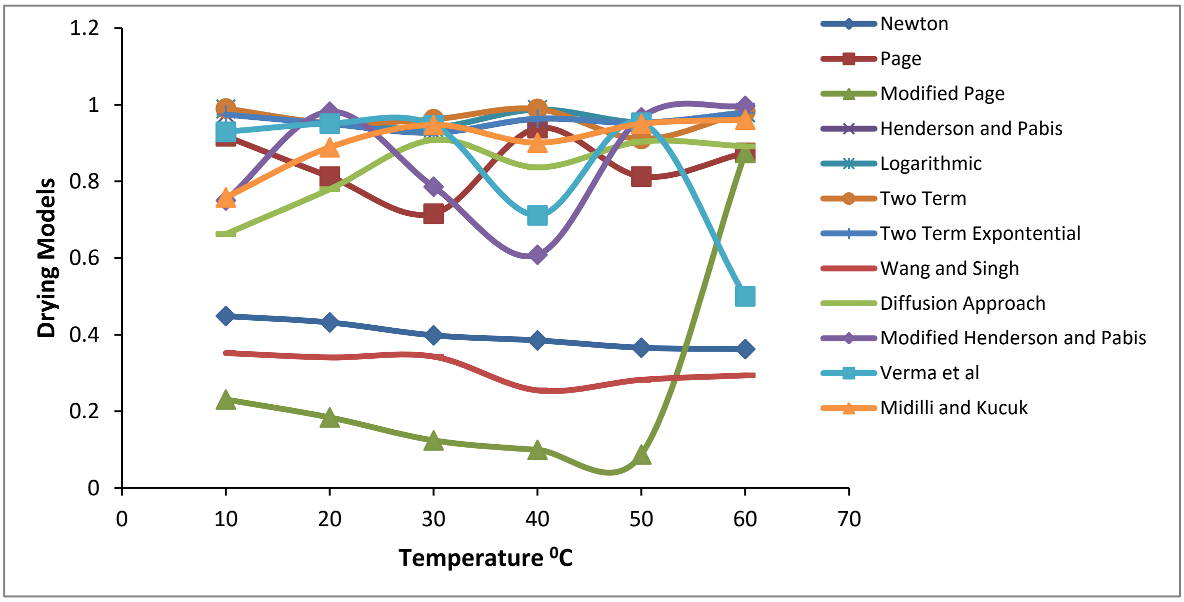

Figure 5 Drying models versus temperature for determination coefficient (Blanched Treatment)

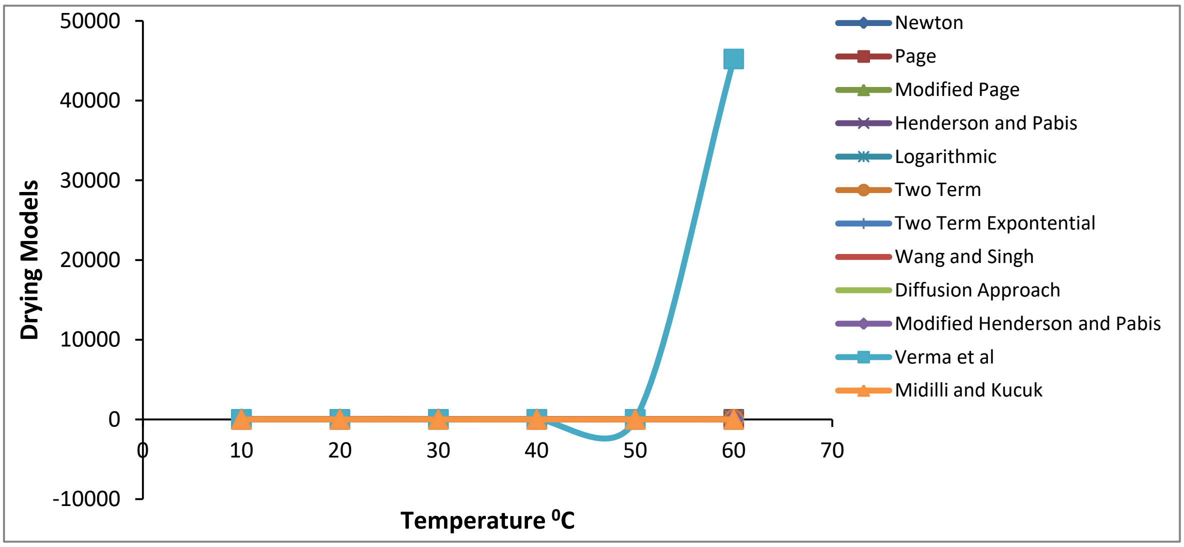

Figure 6 Drying models versus temperature for RMSE (Blanched Treatment)

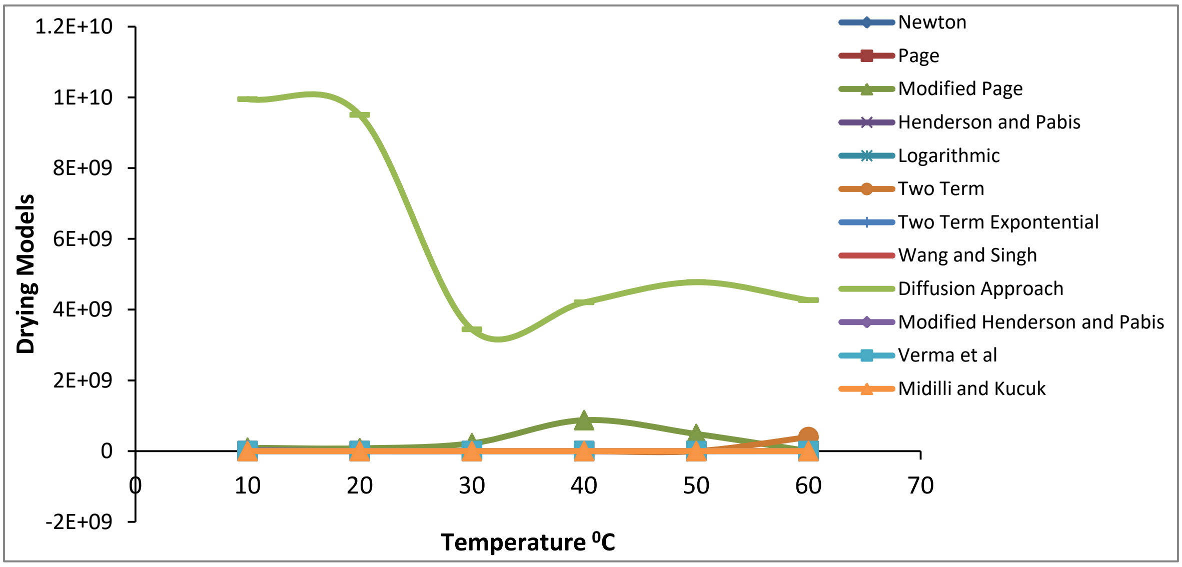

Figure 7 Drying models versus temperature for SEE (Blanched Treatment)

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Figures 5 to 7 were plotted using Table 3. Page, Henderson and Pabis, Logarithmic, two term and two term exponential models can be used to predict the drying characteristics of blanched ginger treatment. Figure 6 showed that Page and logarithmic models have relatively high standard error for estimate. Also, two term model has a very high standard error for estimate at temperature of 60°C. From Figures 4to 7, it can be seen that two term exponential and Henderson and Pabis models are suitable models for predicting the drying characteristics of blanched ginger treatment

VI. CONCLUSION

The drying rate at higher drying times (24 hours) was 0.889/°C and 0.4437/°C for 2 hours drying, giving 50% by moisture reduction rate. The interception which theoretically gives the initial moisture content of 0°C is lower at 24 hours drying (59.33%) compared to 95.12% on dry basis at 2 hours drying, as expected. The average drying time for the variously treated ginger sample is 2.4hours. The significance of drying ginger for a long time at even lower temperature around 60°C has been shown in this work. At higher temperatures ginger shrinkage and surface discoloration may occur. As can be seen, good results are achievable at temperature of 60°C to sustain the quality of the products. The thermal conductivity for 24 hours –dried ginger at 60°C approximates to the thermal conductivity of dried ginger and it is 0.05 W/mk. This study revealed that five drying models can be used to predict the drying characteristics of the various ginger treatments. There are Page, Henderson and Pabis, Logarithmic, two term and two term exponential models. Nevertheless, two terms exponential proved to be the model most suitable for predicting the drying characteristics of ginger rhizome.

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