EFFECT OF SLICE THICKNESS AND TEMPERATURE ON THE DRYING KINETICS OF MANGO *(Mangifera Indica)*

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ABSTRACT

Mango is harvested in abundance during its season in most developing countries. However storage for period of scarcity and conversion to other products are not common hence heavy losses are incurred leading to economic losses as well as environmental pollution. Dried mango is currently being embraced by in most developing countries. Drying characteristics of mango as affected by drying air temperature and slice thickness were therefore studied with a view to understanding the drying kinetics and provide information useful in dryer design. Fresh mangoes were dried at 60, 70 and 80^{o}C at constant thickness and drying air velocity of 3mm and then 3, 6 and 9mm slice thick mangos were dried at constant drying air temperature of 70^{o}C, all velocity of 3.5m s^{-1}. Drying information were fitted into four drying models namely: Newton, Page, Modified Page and Henderson and Pabis. The drying was discovered to have taken place during the falling rate period and Page model described the drying behavior of the mango slices satisfactorily with R^2 of 0.990. The effective moisture diffusivity coefficients increased with increasing temperature ranging between were 3.89 and 6.99 x 10^{-10} with activation energy of 28.95kJ.mol^{-1}. This has provided useful information in dehydration of mango.

Keywords: *Drying kinetics, Drying model, Mango slices, Moisture ratio.*

1. INTRODUCTION

Mango (*Mangifera indica* L.) is one of the most important tropical fruits in the world and currently ranked 5th in total world production among the major fruit crops (FAO, 2004). It is very rich in vitamin A and C. It also provides a certain amount of other vitamins and minerals such as riboflavin, niacin, calcium, phosphorus and iron (Jiménez, 2004). Global production of mangos is concentrated mainly in Asia and more precisely in India being the leading producer in the world. In Nigeria, despite lack of encouragement as to large scale production of tropical fruits, Nigeria still occupies the 8th position in the world ranking of mango producing countries as at 2002 (Sulaimon and Salua, 2007)

Fruits and vegetables, mango inclusive, are regarded as highly perishable food due to their high moisture content (Simal et al., 1994). Accordingly, they exhibit relatively high metabolic activity compared with other plant-derived foods such as seeds. This metabolic activity continues after harvesting, thus making most fruits highly perishable commodities (Atungulu et al., 2004). Consequently after harvest excess mango moisture content must be reduced to a level acceptable for marketing, storage and processing.

Drying is defined as a process of moisture removal due to simultaneous heat and mass transfer (Ertekin and Yaldiz, 2004). Purposely it is carried out to reduce water to the level at which microbial spoilage and deterioration reactions are greatly minimized (Akpinar and Bicer, 2004). Though there are many ways in which drying can be achieved, but the choice of method depend on the material and the sanitary level required. In tropical and sub tropical countries sun drying is rampant; the flaws include intrusion by animal and pest. This invariably reduces the final quality of the product hence the development of convective dryer is being canvassed for. The knowledge of how drying air temperature and slice thickness affect the drying behavior of mango for optimum and efficient dryer design is inevitable.

Dried mango contain phenols, this phenolic compound have powerful antioxidant and anticancer abilities. It can be eaten as snack or as ingredient in bakery and confectionary products. Several works has been done on drying characteristics of agricultural products. They include tomato (Kross et al., 2000), soybean (Gely and Santalla, 2000), eggplant (Ertekin and Yaldiz, 2004), apple (Wang et al., 2006), green pepper and onion (Yaldiz and Ertekin, 2001). Although Goyal et al. (2006) studied the thin-layer drying kinetics of raw mango slice and El-Amin et al. (2008) investigated drying kinetics and colour change of mango slices as affected by drying temperature and time but none of them put the thickness of the mango slices into consideration with respect to time. Time of drying is essential in countries where energy cost is high. The objectives of this work therefore is to study the effects of drying conditions and the slices thickness on the drying behavior of mango slices and to select the most suitable model (in terms of fitting ability to describe the thin-layer drying of mango under such conditions.

2. MATERIALS AND METHODS

A batch dryer developed in the Department of Agricultural and Environmental Engineering, University of Ibadan, Nigeria was used. The dryer consist of a fan with speed regulator giving air speed range of 3.0, 3.5 and 4.0 m s^{-1} and heating chamber consisting of three heater elements for heating air and a thermostat for regulating the temperature within the dryer in the range of 0 - 400°C dry bulb temperature. The walls of the dryer were insulated to minimize heat loss. Products were loaded on the dryer's perforated drying tray 60 cm × 60 cm and weighing was done using an electronic precision balance with a capacity of 5000 g and degree of accuracy of 0.1g (Metra TL-5000). A digital anemometer (AM-4812 Anemometer) with vane probe was used to ascertain the drying air velocity.

Fresh mangos obtained from Ogbomoso, Oyo State, Nigeria were washed and sliced into 3, 6 and 9 mm thickness. The drying air velocity was adjusted to 3.5 m s^{-1} and the drying was done at air temperatures of 60, 70 and 80°C to study the effect of temperature for 3mm thickness. Samples were thereafter dried at 70°C for thicknesses of 3, 6 and 9 mm for effect of thickness. The average initial moisture content was determined by the gravimetric (oven-dried) method as determined by convective air drying at 135°C for 2 h (AOAC, 2000) in an oven. For each experiment 150 g of the samples were dried in triplicate and the average taken. Weight loss was recorded at an interval of 30 minutes and the temperature in the oven was monitored with a thermometer until weight loss is constant.

Based on the initial moisture content from oven drying, the weight loss was used to calculate the moisture content using Equations 1 and 2.

$$DM = \frac{M}{1+MC_{db}} \tag{1}$$

$$MC_{db} = \frac{M}{DM} - 1 \tag{2}$$

where DM is the Dry matter content (g), MC_{db} is the average initial moisture content (%db), M is mass of wet product (g) and MC_{db} the moisture content at time t (%db).

The moisture content information were converted to the dimensionless moisture ratio (MR) according to Pala et al (l996), Doymaz (2004) and Diamente and Munro (1993) in Equation 3

$$MR = \frac{M-M_e}{M_0-M_e} \tag{3}$$

where M is Moisture content at time t (%db); M_o is the initial moisture content, (%db) and M_e is the equilibrium moisture content (%db)

The drying kinetics of the mango samples were tested by fitting the drying data to four models presented in Table 1. Non-linear regression analysis was used for fitting the four mathematical drying models to the experimental data. Comparison criteria used to evaluate goodness of fit include mean bias error (MBE), Root mean square error (RMSE), reduced chi-square χ^2 and coefficient of determination R^2.Linear regression technique was used to obtain the model coefficients and constants by fitting the models into experimental data. The RMSE gives the deviation between the predicted and experimental values and it is preferred to reach to zero, chi-square is the mean square of the deviations between the experimental and predicted values by the models and was used to determine the goodness of the fit. The lower the value of the RMSE and reduced chi-square the better is the fit.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(MR_{pre} - MR_{\exp}\right)^2}{N}} \tag{4}$$

$$\chi^2 = \sum_{i-1}^{n} \frac{\left(MR_{\exp} - MR_{pre}\right)}{N-n} \tag{5}$$

where exp. represents experimental data and pred. is predicted data, N is number of observations and n is Number of constants

Effective moisture diffusivity and Activation Energy

Effective moisture diffusivity (D_{eff}) was calculated using Fick's second equation of diffusion as reported by Crank (1975) considering a constant moisture diffusivity, infinite slab geometry, and a uniform initial moisture distribution (Crank 1975). The crank equation for slab which involved a series of exponents can be simplified to Equation 6 using the first term. Further detailed discussions can be found in Jena and Das (2007) and Aghbashlo (2011).

$$MR = \frac{8}{\pi^2}\exp\left(\frac{-\pi^2 D_{eff}}{4L^2}t\right) \tag{6}$$

where, MR is the moisture ratio, D (m^2s^{-1}) is the effective moisture diffusivity, L (m) is the sample thickness and t is the drying time (s).

Therefore $\ln(\mathrm{MR}) = \frac{-\pi^2 D_{eff}}{4L^2} t + \ln\frac{8}{\pi^2}$ (7)

The effective diffusivity (D_{eff}) at each temperature was obtained from the slope of the plot of Ln(MR) against time for corresponding temperature data. The energy of activation was calculated by using an Arrhenius type equation (Menges and Ertekin 2006; Kashaninejad et al., 2007; Aghbashlo et al., 2008). As reported by Ojediran and Raji (2011), the diffusivity coefficient at different temperatures is often found to be well predicted by the Arrhenius equation given by:

$$D_{eff} = D_o e^{-\frac{Ea}{R_g\,(T+273.15)}} \quad (8)$$

D_o is the maximum diffusion coefficient (at infinite temperature), E_a is the activation energy for diffusion (kJ mol^{-1}), T is the temperature (^oC) and R_g is the gas constant. Linearizing Equation 8 gives:

$$\ln D_{eff} = \left(-\frac{1}{R_g\,(T+273.15)}\right)Ea + \ln D_o \quad (9)$$

In a similar manner to D_{eff}, the energy of activation was obtained as the slope of the plot of ln D_{eff} against $\left(-\frac{1}{R_g\,(T+273.15)}\right)$

3. RESULTS AND DISCUSSION

The drying air temperature is one among the main factors influencing the drying kinetic of mango slices at constant slice thickness as can be deduced from Figure 1. An increment in drying air temperature was accompanied by reduction in time taken to reach equilibrium moisture content. Equilibrium moisture content was reached at 6.5, 5.5 and 4 hours for samples dried at 60, 70 and 80^oC respectively. The constant rate drying was not well pronounced as the drying took place at the normal falling rate for the three temperatures tested

Slice thickness also was another main factor affecting the drying characteristics of mango slices at fixed temperature. According to Figure 2 the drying time increased as the slice thickness increase. When 3 mm thick mango slices were dried the equilibrium moisture content was attained at 330 min at 70^oC drying temperature and 3.5 m s^{-1} drying velocity. This moisture level was reached after 360 and 390 min with 6 and 9 mm slice thickness respectively.

The drying rate reached its maximum as shown in Figures 3 and 4 at drying air temperatures of 80^oC and lowest slice thickness of 3 mm. After that, drying rate decreased under both drying condition. This was because at the highest temperature and lowest thickness the free moisture was rapidly removed or evaporated corresponding to high drying rate at the initial stage of drying, the reduction in the drying rate subsequently witnessed was as a result of the movement of moisture from the core of the slices to the surface before evaporation. This led to decreased drying rate toward the equilibrium moisture content. The drying processes occurred in falling rate drying period indicating that internal mass transfer has occurred by diffusion starting from initial moisture content of 81.5%wb to equilibrium moisture content. Similar results have been reported by Goyal et al. (2006) and el-Amin et al. (2009) for mango fruit and for some other fruits and vegetables (Akpinar, 2006; Akanbi et al. 2006). The most effective force governing the moisture movement was diffusion.

The regression results presented in Table 2 show that Page model gave the lowest value of RSME, MBE and χ^2 compared to the other three models. It also has the highest value of R^2 and thus it is the model that best fit the drying of mango slices. The Page model's fitness was further validated by plotting the experimental moisture ratio values against the predicted as presented in Figures 5 and 6 for slice thicknesses 3 and 9 mm respectively and the plot of the models prediction against the experimental data (only 80^oC shown) presented in Figure 7.

The experimental and predicted moisture ratio values lay around the straight line which fits perfectly with a straight line dividing the plot area to two equally. This is evident from the equations as presented in Figures 5 and 6 having slope of approximately one and intercept of almost zero. In Figure 7, only page model curve has the least variations from the experimental points as compared to others. This clearly demonstrates that this model could be used to explain the thin layer drying behaviour of mango. Goyal et al. (2006) and El-Amin et al. (2008) reported similar results for air drying of mango slices.

The D_{eff} obtained, from slope of the linear graphs in Figure 8 according to Equation 7 were 3.89 x 10^{-10}, 4.86 x 10^{-10} and 6.99 x 10^{-10} respectively for 60, 70 and 80^oC for 3 mm thickness. This shows that the D_{eff} increases with increasing temperature. The coefficients of determination for the three are greater than 0.95 implying a good fit. This implies that as reported by Ojediran and Raji (2011), this could be as a result of the fact that water diffusion was mainly due to mass transport mechanism during the first phase of drying. The moisture from the inner core of

the product migrates and replaces the surface and capillary moisture as they evaporated and eventually diffusion of moisture became the predominant mechanism.
The energy of activation was obtained from the slope of the straight line in Figure 8 according to Equation 9 as 28.95 kJ mol^{-1}. Activation energy is a measure of the temperature sensitivity of D_{eff} and it is the energy needed to initiate the moisture diffusion within the slice. The activation energy is within the general range of 12.7 -110 kJ mol^{-1} (Zogzas et al., 1996) for most high moisture agricultural and food materials as presented by several other reports; 16-32 kJ mol^{-1} for tomatoes (Doymaz, 2007), 21 - 26 kJ mol^{-1} for banana (Thuwapanichayanan et al., 2008), 38.6 kJ mol^{-1} for kiwi fruit (Orikasa et al., 2008). The value is however lower than those of harder high moisture crops such as red chilli drying (41.95 kJ mol^{-1}) (Gupta et al., 2002) and okra (51.26 kJ mol^{-1}) (Doymaz, 2005).

4. CONCLUSIONS

This study established that the drying behavior of for mango slices occur in the falling rate period and Page model best explain the drying characteristics. A smaller thickness of 3 mm with higher temperature of 80°C is the best condition for drying of mango being a high moisture product. The study has therefore provided information useful in drying process design for mangos which will assist in reducing losses often incurred during bumper harvesting and processing of mangoes.

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Table1: Selected drying models for describing mango slices drying data

Model Name	Equation	References
Newton	MR= exp (-kt)	Lewis, 1921
Page	MR= exp ($-kt^n$)	Page, 1949
Henderson and Pabis	MR= a exp (-kt)	Henderson and Pabis,1961
Modified Page	$MR = aexp[-(kt)^n]$	Yaldız et al., 2001

Table 2: Model coefficients and constants for drying of mango

Model	A	k	n	R^2	χ^2	RMSE	MBE
Page	-	0.0138	0.9818	0.9904	0.0075	0.0034	0.0021
Newton	-	0.0067	-	0.9739	0.0162	0.0479	0.0025
Modified Page	-	0.0075	0.9903	0.9833	0.0033	0.0405	0.0015
Herderson and Pabis	0.8017	-	0.0057	0.9531	0.0113	0.0618	0.0046

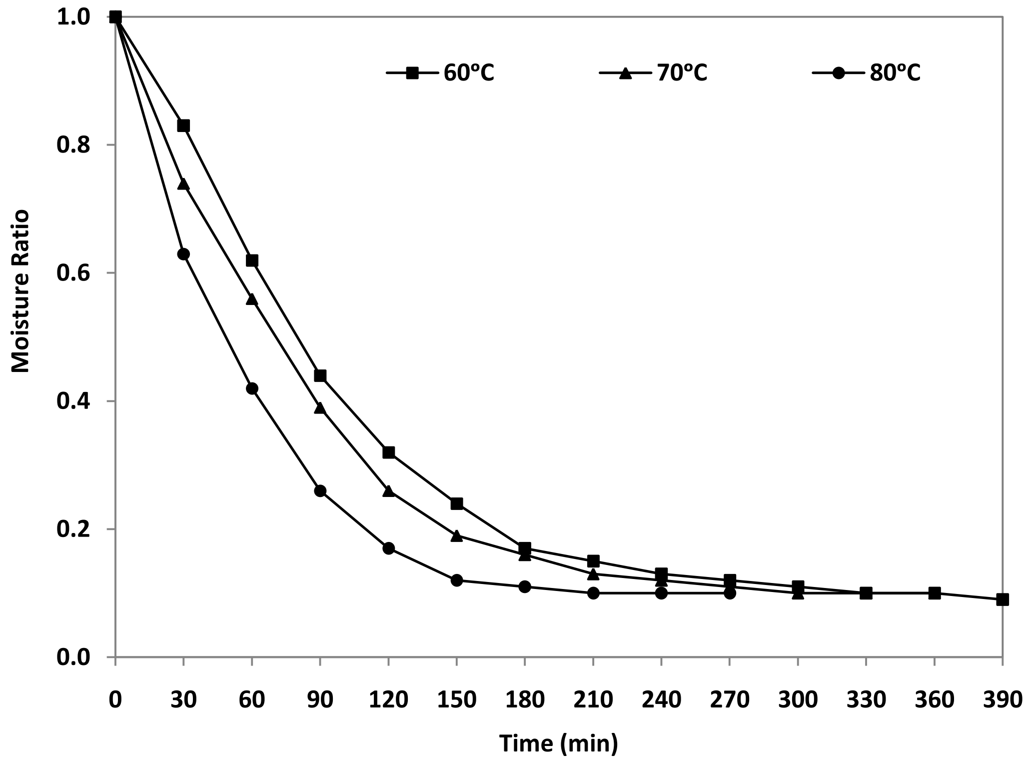

Figure 1: Effect of drying air temperature for 3 mm thick slices

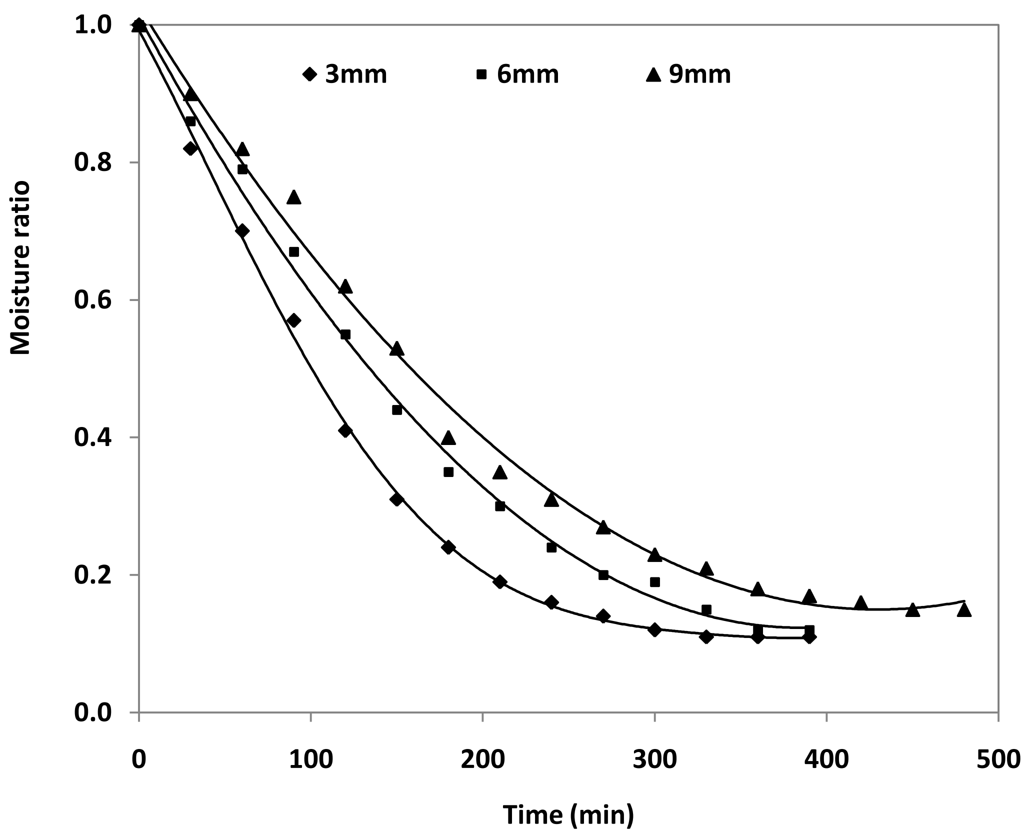

Figure 2: Effect of slice thickness on drying at 70°C drying temperature

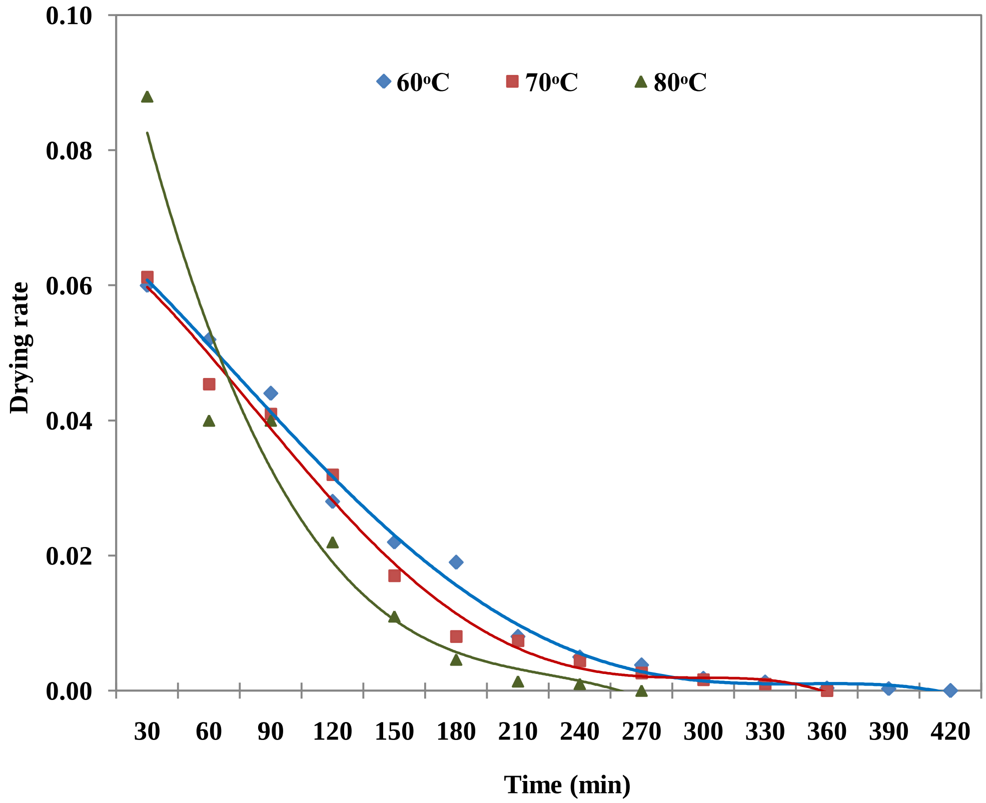

Figure 3: Drying rate for mango slices at different temperature setting.

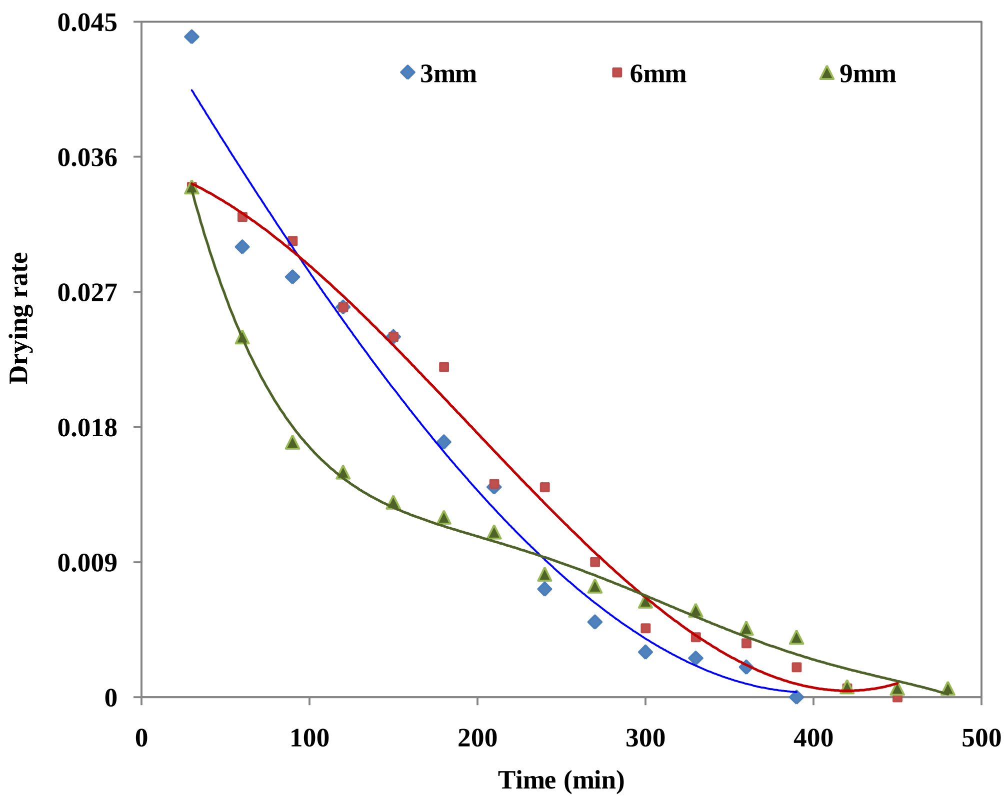

Figure 4: Drying rate curves for mango at different slice thicknesses

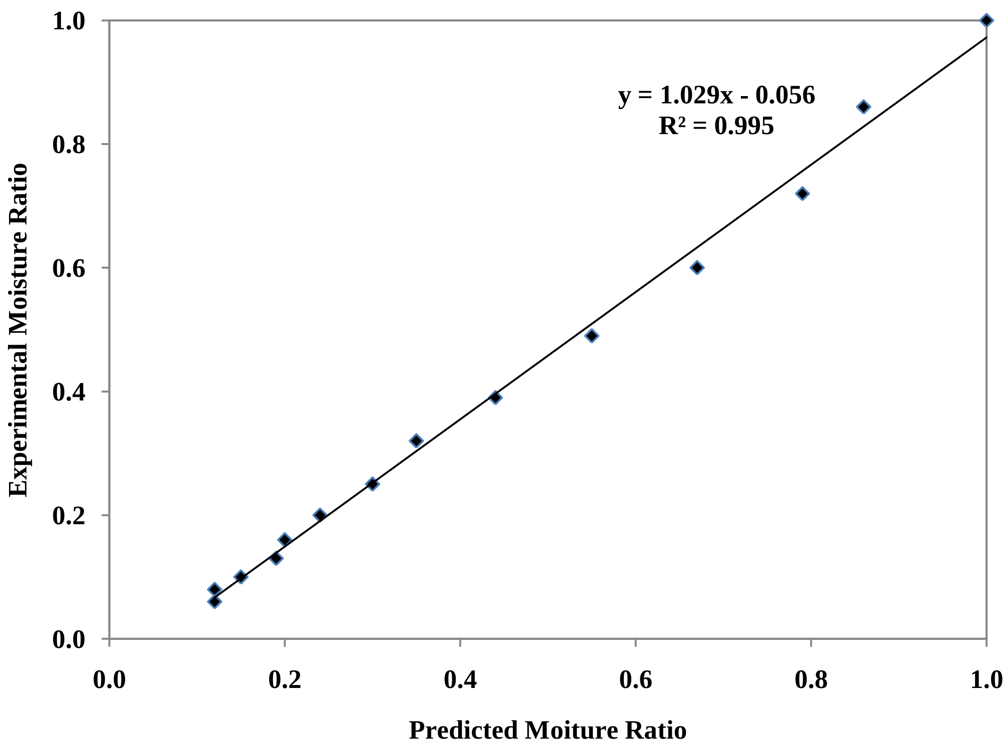

Figure 5: Page model fitting for 80°C, 3 mm slice thickness

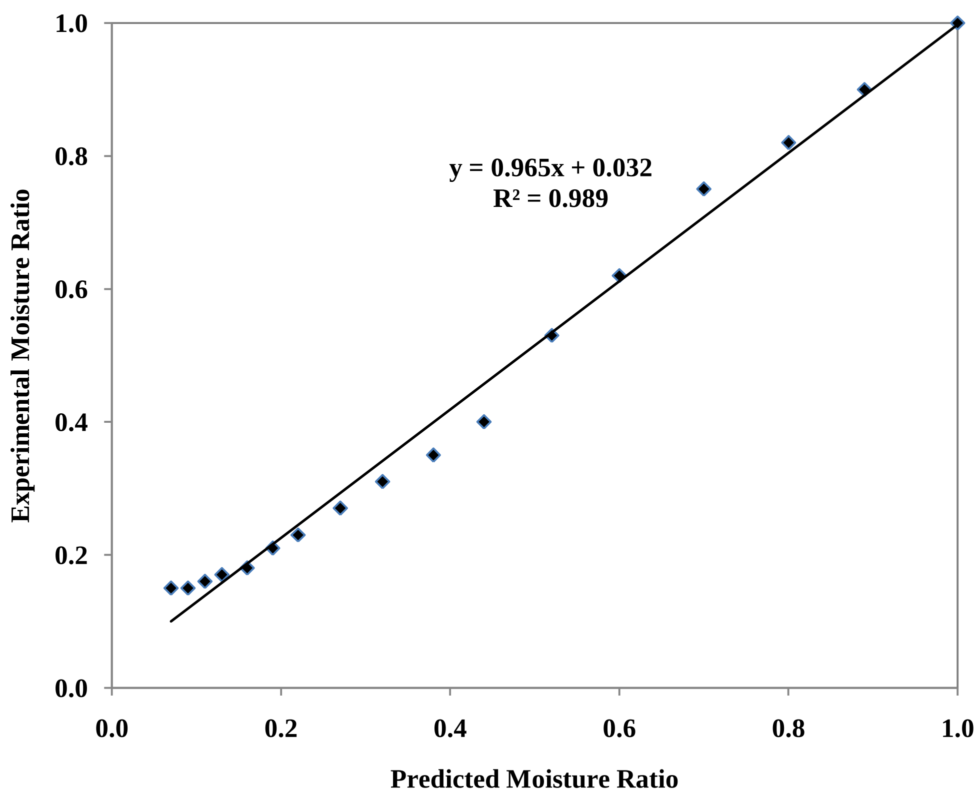

Figure 6: Page Model fitting for 70°C, 9 mm slice thickness

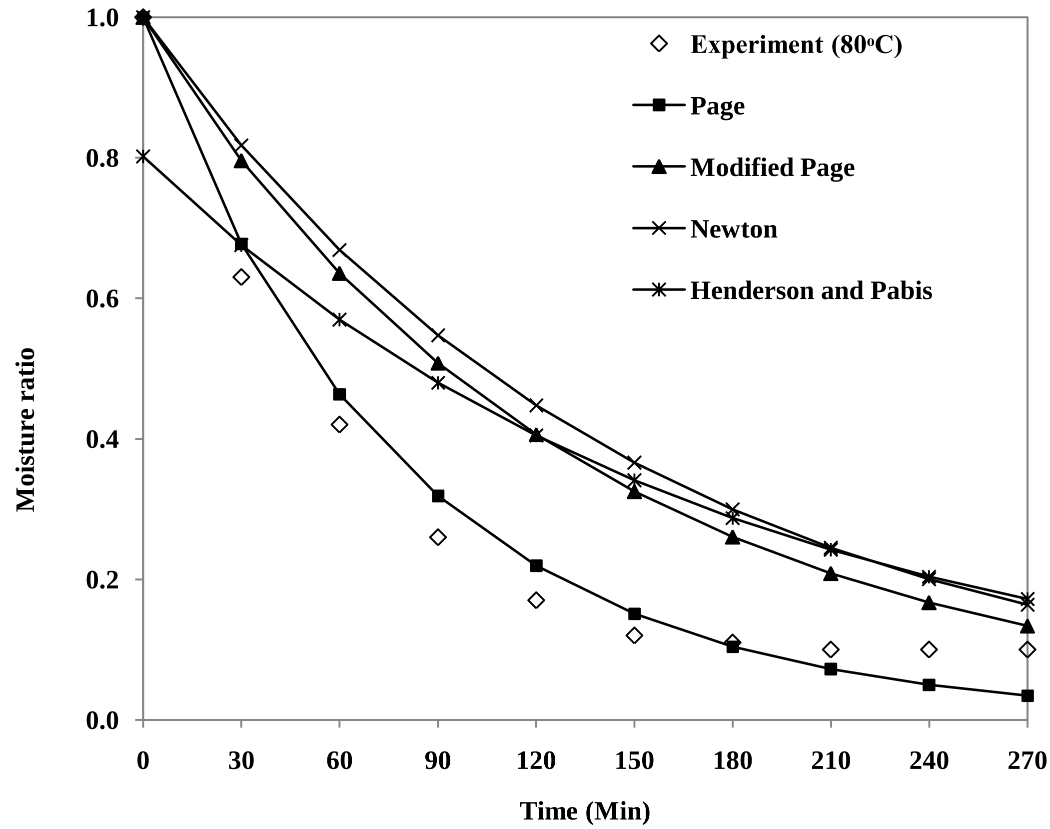

Figure 7. Models prediction with the experimental data at 80°C for 3 mm thickness

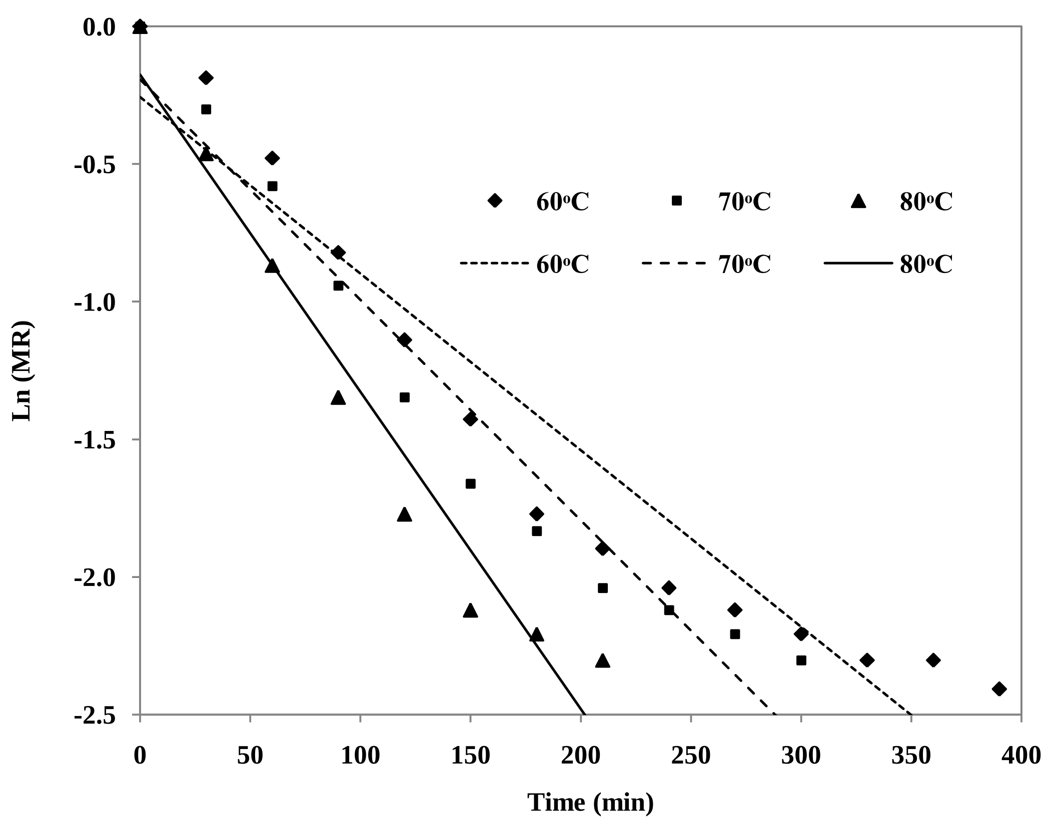

Figure 8. Estimation of Moisture Diffusivity Coefficient

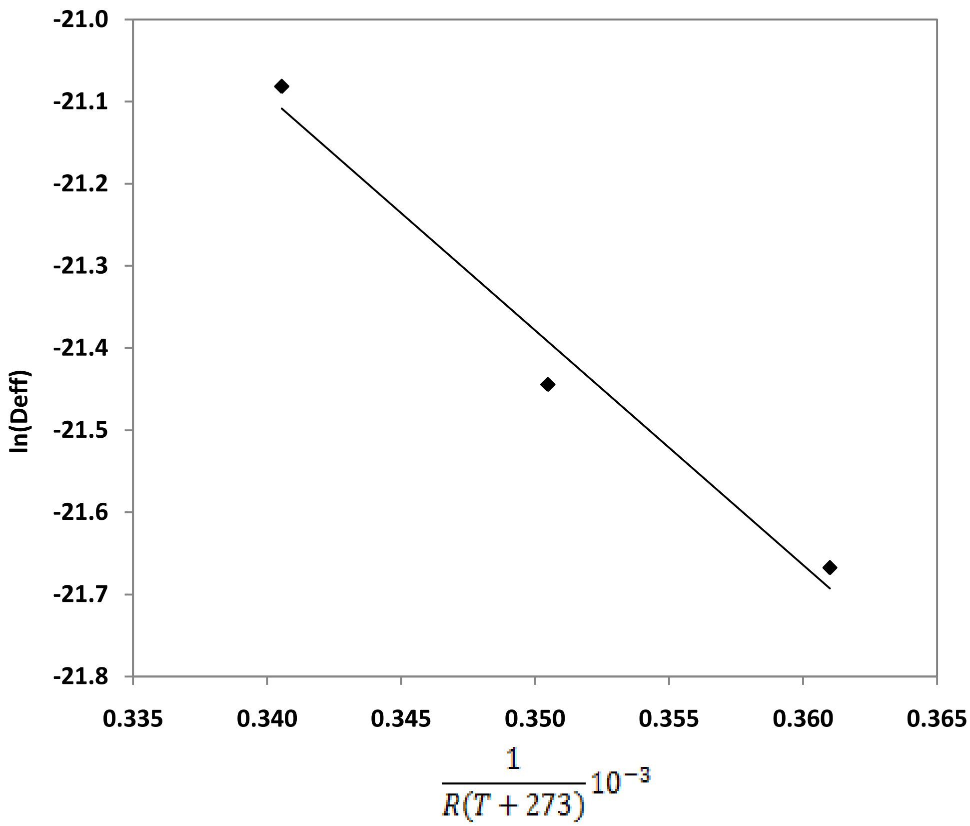

Figure 9. Estimation of Activation Energy