Drying Kinetics Studies of Onion (*Allium cepa L.*)

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Abstract: Drying using a hot air chamber was tested on onion (*Allium cepa L*.). The drying experiments were performed at different temperature of 45°C, 50°C and 55°C and a constant air velocity of 1 m/s. Drying kinetics of *A. cepa* were investigated and obtained. A non-linear regression procedure was used to fit three drying models of thin layer drying models. The models were compared with experimental data of *A. cepa* drying at relative humidity of 15%. The fit quality of the models was evaluated using the coefficient of determination (R^2), Mean Bias Error (MBE) and Root Mean Square Error (RMSE). The highest values of R^2 (0.9797), the lowest MBE (0.0006) and RMSE (0.0242) indicated that the Page model is the best mathematical model to describe the drying behavior of onion (*A. cepa*).

Keywords: Drying kinetics, *Allium cepa L*, onion, hot air chamber, mathematical modeling

1 Introduction

Most agricultural commodities require drying process in an effort to preserve the quality of the final product. The quality of the products depends on many factors including the drying temperature and duration of drying time [1]. Hot air drying is the most frequently used dehydration operation in the food and chemical industry. Recently, there have been many reports on drying kinetics of agricultural fruits and vegetables. Thin-layer drying models also have been widely used for analysis of drying of various agricultural products [2-5]. Fudholi et al. [6] reported the effects of drying air temperature and humidity on the drying kinetics of seaweed *Gracilaria cangii*. The drying kinetics of *G. cangii* was studied using solar drying system [7] whereas hot air chamber was used to determine the drying kinetics of brown seaweed *Eucheuma cottonii* [8].

The objectives of this study are to propose mathematical model for drying curves and to determine the effect of drying air temperature on drying behavior of onion. Onion is one of the spices that has been the main ingredient in all cooking and also has high nutritional value. The use of onion is not just for adding food palatability, because there are a number of studies have shown that onion is very beneficial for human health. Onion is one of the agricultural commodities that have an important role although not as important as rice. Onions are very sensitive to weather conditions. If not treated properly, onion harvested will be a quick wilt disease. This will results in poor quality onion and gives loss to farmers.

According to recent researches, the drying time for onions is 24 to 48h, and maximum allowable temperature is 55°C. The onions should be dried until its moisture content achieved 6 to 10% with initial moisture content is 80 to 85% [9].

2 Material and Methods

The experiments are carried out at the Solar Energy Laboratory in Physics Department, Universiti Kebangsaan Malaysia. In this study, a hot air chamber was used to investigate the drying kinetics of onions. The hot air chamber (Model DY110, Angelantoni Asean Pte Ltd, Singapore) is capable of providing the desired drying air temperature in the range of -40 °C to 180°C and air relative humidity in the range of 10% to 98%. Onion after been cleaned and be cut into ±1.0cm was inserted into the chamber. The drying experiments were conducted at drying air temperature of 45°C, 50°C and 55°C and at relative humidity (RH) 15%, and constant air velocity of 1 m/s. The change of weight was recorded at every 5 minutes. Measurement was discontinued when the heavy weight of the material reaches a constant fixed value. Data obtained from the measurements of weight in a test prior to being used for the analysis of drying kinetics of materials need to be changed first in the form of moisture content data. The moisture content was expressed as a percentage wet basis, and then converted to gram water per gram dry matter. The experimental drying data for onions were fitted to the exponential model thin layer drying models as shown in Table 1 by using non-linear regression analysis.

Table 1. Four one-term exponential model thin layer drying models

No.	Model name	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)

The moisture ratio (MR) can be calculated as

$$MR = \frac{M - M_e}{M_0 - M_e} \quad (1)$$

where,
Me = Equilibrium moisture content
Mo = Initial moisture content

The moisture content of materials (M) can be calculated using two methods on the basis of either wet or dry basis using the following equation. The moisture content wet basis

$$M = \frac{w(t) - d}{w} x100\% \quad (2)$$

The moisture content dry basis

$$X = \frac{w(t) - d}{d} \quad (3)$$

where,
w(t) = mass of wet materials at instant t
d = mass of dry materials

The coefficient of determination (R^2) was one of the primary criteria to select the best model to compare with the experimental data. In addition to R^2, mean bias error (MBE) and root mean square error (RMSE) were also used to compare the relative goodness of the fit. The best model describing the drying behavior of onion was chosen as the one with the highest coefficient of determination and the least root mean square error [10,11]. This parameter can be calculated as follow:

$$MBE = \frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{\exp,i}\right)^2 \quad (4)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{\exp,i}\right)^2\right]^{\frac{1}{2}} \quad (5)$$

3 Results and Discussion

The results of the drying kinetic curves of onion at the relative humidity of 15% and air temperature of 45^{o}C, 50^{o}C and 55^{o}C are shown in Fig. 1 to Fig. 4. It consists of three curves namely the drying curve, the drying rate curve and the characteristic drying curve. Drying curve showed the profile change in moisture content (X) versus drying time (t). Drying rate curve illustrated the drying rate profile (dX/dt) versus drying time (t). Drying characteristic curves displayed the drying rate profile (dX/dt) versus moisture content dry basis (X).

Fig. 1 and Fig. 2 showed a decrease in moisture content wet basis and dry basis of drying time at different temperature at relative humidity 15%, respectively. From these graphs, it shows that if the drying temperature is low causes the drying time become longer. In contrast to the higher drying time, the moisture content will be rapidly reduced.

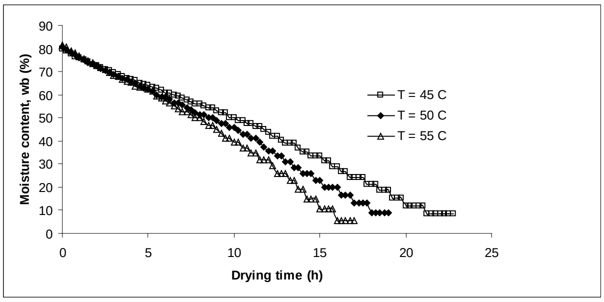

Fig.1. Moisture content variation with drying time at 15% RH and air velocity of 1 m/s

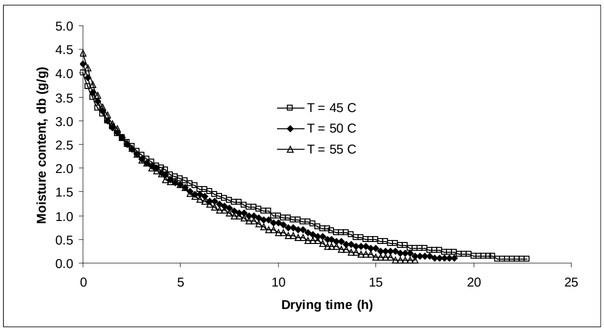

Fig. 2. Drying curve: dry basis moisture content versus drying time at 15% RH and air velocity of 1 m/s

Fig. 3 showed the profile of the drying rate versus drying time. From this graph, the drying rate was found higher at high temperature. This means that the time required to dry the material to reach equilibrium moisture content is shorter. Fig. 4 showed the characteristic drying curve obtained at different temperature.

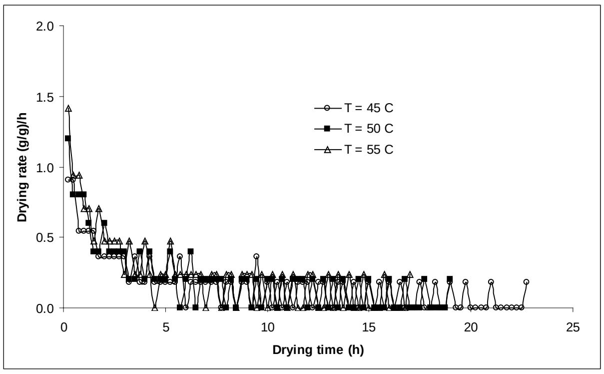

Fig. 3. Drying rate curves: dry basis moisture content versus drying time at 15% RH and air velocity of 1 m/s

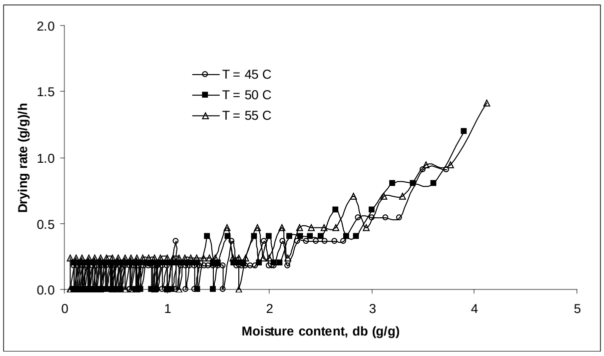

Fig. 4. Drying characteristic curves: a dry basis moisture content versus drying time at 15% RH and air velocity of 1 m/s

Fitting of the four drying models has been done with the experimental data of onion at 15% RH and temperature of 45°C, 50°C and 55°C. Drying models which were fitted with the experimental data of drying were the Newton model, Page model and Henderson and Pabis model. Drying experimental data fitted the model of drying in the form of changes in moisture content versus drying time. In these drying models, changes in moisture content versus time were calculated using Excel software, and constants were calculated by graphical method. The results that fitted with the drying models with experimental data were listed in Table 2. This table showed a constant drying and precision fit for each model of drying. The one with the highest R^2 and the lowest MBE and RMSE was selected to better estimate the drying curve. Page equation can also be written as the following equation

$$\ln(-\ln MR) = \ln k + n \ln t \quad (6)$$

Equation 6 is the relationship ln (-ln MR) versus t, is the curve of the logarithmic equation, as shown in Fig. 6. Henderson and Pabis equation can also be written as the following equation

$$\ln MR = -kt + \ln a \quad (7)$$

From equation 7, a plot of ln MR versus drying time gives a straight line with intercept = ln a, and slope = k. Graf MR versus ln t, as shown in Fig. 7, obtained the value k = 0.2383 and the value of a = 1.1504. Results presented in Table 2 showed that the Page drying model has the highest value of R^2 (0.9797), as well as the lowest values of MBE (0.0006) and RMSE (0.0242), compared to Newton's model and Henderson and Pabis model. Accordingly, the Page model was selected as the suitable model to represent the thin layer drying behaviour of onion. This is in accordance with Fudholi et al. [6-8] that Page model was shown to be a better fit to drying seaweed among other one-term exponential model thin layer drying models. On the other hand, as far as the drying behavior of lemon grass is concerned, the Newton model was showed a better fit to the experimental data among other semi-theoretical models [11].

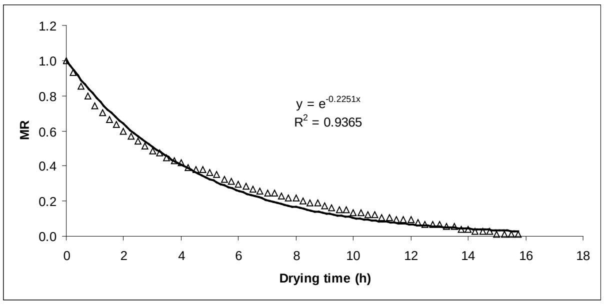

Fig. 5. Plot of MR versus drying time (Newton's model) at temperature of 55°C

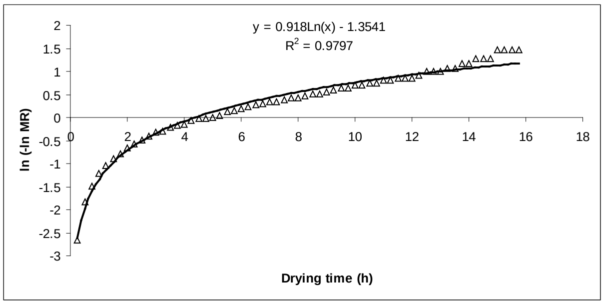

Fig. 6. Plot of ln (-ln MR) versus drying time (Page's model) at temperature of 55^{o}C

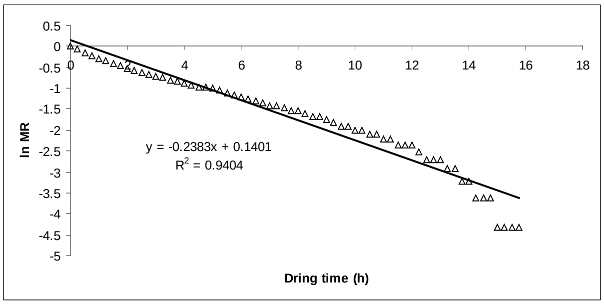

Fig. 7. Plot of ln MR versus drying time (Henderson and Pabis model) at temperature of 55^{o}C

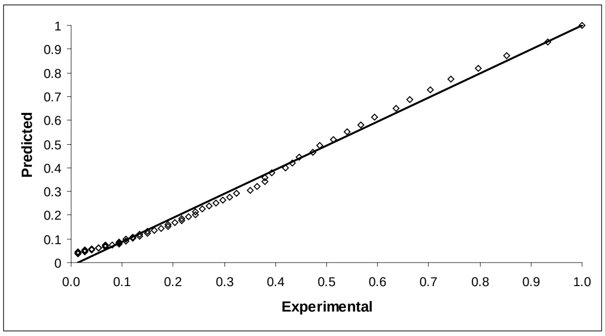

Fig.8. Comparison of experimental MR with predicted MR from Page's model at temperature of 55^{o}C

4 Conclusion

Drying using a hot air chamber was tested on samples of onion (*Allium cepa L.*). Drying kinetics curves of drying onion demonstrated that drying at 55^{o}C and relative humidity of 15% were the optimum values for drying onion, with the appropriate equations using the Page's model drying equation MR =exp(-0.2582t$^{0.918}$) that produced 97.97% accuracy. According to the results which showed the highest average values of R^2 and the lowest average values of MBE and RMSE, therefore it can be stated that the Page model could describe the drying characteristics of onion in the drying process at a temperature of 55^{o}C and relative humidity of 15% and air velocity of 1 m/s.

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References:

[1] A. Fudholi, M. Y. Othman, M. H. Ruslan, M. Yahya, A. Zaharim and K. Sopian, "Techno-economic analysis of solar drying system for seaweed in Malaysia," in *Proc. of the 7th IASME/WSEAS Int. Conf. on Energy, Environment, Ecosystems and Sustainable Development (EEESD,11)*,France, 2011.

[2] A. Mohammadi, S. Rafiee, A. Keyhani and Z. Emam-Djomeh, Estimation of Thin-layer Drying Characteristics of Kiwifruit (cv. Hayward) with Use of Page's Model, *American-Eurasian J. Agric. & Environ. Sci.*, 3(5), 2008, pp.802-805.

[3] A.Taheri-Garavand. S. Rafiee and A. Keyhani, Mathematical Modeling of Thin Layer Drying Kinetics of Tomato Influence of Air Dryer Conditions. *International Transaction Journal of Engineering, Management & Applied Sciences & Technologies*, 2 (2), 2011, pp. 147-160.

[4] S. Gorjian, T. Tavakkoli Hashjin, M.H. Khoshtaghaza and A.M. Nikbakht, Drying Kinetics and Quality of Barberry in a Thin Layer Dryer. *J. Agr. Sci. Tech*, 13, 2011, pp. 303-314.

[5] M. Tahmasebi, T. Tavakkoli Hashjin, M.H. Khoshtaghaza and A.M. Nikbakht, Evaluation of Thin-Layer Drying Models for Simulation of Drying Kinetics of Quercus (*Quercus persica* and *Quercus libani*). *J. Agr. Sci. Tech*, 13, 2011, pp. 155-163.

[6] A. Fudholi, M. Y. Othman, M. H. Ruslan, M. Yahya, A. Zaharim and K. Sopian, "The effects of drying air temperature and humidity on drying kinetics of seaweed", in *Recent Research in Geography, Geology, Energy, Environment and Biomedicine,* Corfu, 2011, pp. 129-133.

[7] A. Fudholi, M. Y. Othman, M. H. Ruslan, M. Yahya, A. Zaharim and K. Sopian, "Design

and testing of solar dryer for drying kinetics of seaweed in Malaysia," in *Recent Research in Geography, Geology, Energy, Environment and Biomedicine,* Corfu, 2011, pp. 119-124.

[8] A. Fudholi, M. H. Ruslan, L.C. Haw, S. Mat, M. Y. Othman, A. Zaharim and K. Sopian, "Mathematical modeling of Brown Seaweed Drying Curves", in in *WSEAS Int. Conf. on Applied Mathematics in Electrical and Computer Engineering,* USA, 2012, pp. 207-211.

[9] A. Fudholi, K. Sopian, M. H. Ruslan, M.A. Alghoul, and M. Y. Sulaiman, Review of solar dryers for agricultural and marine products, *Renewable & Sustainable Energy Review*, vol. 14, 2010, pp. 1-30.

[10] M. Y. Othman, A. Fudholi, K. Sopian, M. H. Ruslan, and M. Yahya, "Analisis Kinetik Pengeringan Rumpai Laut *Gracilaria cangii* Menggunakan Sistem Pengering Suria (Drying Kinetics Analysis of Seaweed *Gracilaria cangii* using Solar Drying System)" *Sains Malaysiana*, vol. 41, no. 2, 2012, pp. 245-252.

[11] M. Ibrahim. K. Sopian and W.R.W. Daud, Study of the drying Kinetics of lemon Grass, *American Journal of Applied Sciences* 6(6), 2009, pp.1070-1075.

Table 2. Results of non-linear regression analysis

Model name	T (^{o}C)	Model Coefficients and Constants	R^2	RMSE	MBE
Newton	45	k = 0.1700	0.9354	0.0377	0.0014
	50	k = 0.1976	0.9488	0.0332	0.0011
	55	k = 0.2251	0.9365	0.0317	0.0010
Page	45	k = 0.2101; n = 0.8947	0.9719	0.0295	0.0009
	50	k = 0.2431; n = 0.8953	0.9787	0.0253	0.0006
	55	k = 0.2582; n = 0.9180	0.9797	0.0242	0.0006
Henderson and Pabis	45	k = 0.1827; a = 1.2134	0.9415	0.0845	0.0071
	50	k = 0.2083; a = 1.1460	0.9522	0.0665	0.0044
	55	k = 0.2383; a = 1.1504	0.9404	0.0652	0.0043