The Effects of Drying Air Temperature and Humidity on the Drying Kinetics of Seaweed

A. Fudholi, M. Y. Othman, M. H. Ruslan, M. Yahya, A. Zaharim and K. Sopian

Abstract— A Low Temperature and Humidity Chamber Test tested in the Solar Energy Laboratory, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, Selangor, Malaysia. Experiments are carried out to study the effect of drying air temperature and humidity on the drying kinetics of seaweed and to develop a model to estimate the drying curves. Simple method using a excel software is used in the analysis of raw data obtained from the drying experiment. The values of the parameters a, n and the constant k for the models are determined using a plot of curve drying models. Three different drying models are compared with experiment data seaweed drying at 40, 50 and 60°C and relative humidity 10, 25 and 40%. The higher drying temperatures and low relative humidity the moisture content will be rapidly reduced. The most suitable model is selected to best describe the drying behavior of seaweed. The values of the coefficient of determination (R^2), mean bias error (MBE) and root mean square error (RMSE) are used to determine the goodness or the quality of the fit. The Page model is showed a better fit to drying seaweed among Newton model and Henderson and Pabis model.

Keywords— Drying kinetics, drying modeling, seaweed.

I. Introduction

DRYING process plays an important role in the preservation of agricultural products (Saeed et al., 2008). Air drying is the most frequently used dehydration operation in the food and chemical industry (Ibrahim et al., 2009; Saeed et al., 2008). The wide variety of dehydrated foods, which today are available to the consumers and the interesting concern for meeting quality specifications and energy conservation, emphasize the need for a through understanding of the drying process.

Mathematical modeling of thin layer drying is important for optimum management of operating parameters and prediction performance of drying process. It is essential to set out accurate models to simulate the drying curves under different drying conditions. The description and prediction of the drying kinetics of a given material is still a weakness in the modeling of drying process. There is a great need for stable and reliable model to quantify and predict drying rates and drying times with a satisfying accuracy (Saeed et al., 2008a; Saeed et al., 2008b).

Drying kinetics is generally evaluated experimentally by measuring the weight of a drying material a function of time. Drying curves may be represented in three different types of plots that are moisture content versus time, drying rate versus time and drying rate versus moisture content.

The objective of this study are to propose mathematical model for the drying curves and to determine the effects of drying air temperature and humidity on the drying behavior of seaweed.

II. Material and Methods

Fig. 1 shows photograph Low Temperature and Humidity Chamber Test in the Solar Energy Laboratory of the Faculty of Science and Technology Universiti Kebangsaan Malaysia. It used to investigate the kinetics of drying seaweed. The variable of the experiments are drying air temperature and humidity. Three drying air temperatures (40, 50 and 60°C), and three relative humidity (10, 25 and 40% RH) are applied. Air velocity is kept constant at 1 m/s for all experiments.

Fig. 1 Photograph Low Temperature and Humidity Chamber Test

Seaweed after cleaning chamber inserted into the hair. The air velocity in a chamber dryer set 1 m/s, while temperature and relative humidity set in the range of 40°C to 60°C and 10% to 40%. The change of weight recorded every 5 minutes. Measurement is discontinued when the heavy weight of the material reaches a constant value. Data obtained from measurements in a test that measured the weight of the time before being used for the analysis of drying kinetics of materials need to be changed first in the form of moisture

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A. Fudholi, M. Y. Othman, M. H. Ruslan, M. Yahya, A. Zaharim and K.Sopian is with the Solar Energy Research Institute, Universiti Kebangsaan Malaysia, 43600 Bangi Selangor, MALAYSIA.
(E-mail: fudholi.solarman@gmail.com, azami.zaharim@gmail.com, ksopian@eng.ukm.my)

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

$$M = \frac{w(t) - d}{w} x100\% \qquad (1)$$

The moisture content dry basis (Dissa et al. 2009)

$$X = \frac{w(t) - d}{d} \qquad (2)$$

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

To determine the kinetics of drying seaweed, drying model is used. Table 1 shows there are some drying models.

Table 1. Several models of drying (Aktas et al. 2009; Ibrahim et al. 2009)

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 (Ibrahim et al. 2009)

$$MR = \frac{M - M_e}{M_0 - M_e} \qquad (3)$$

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

Initial moisture content of seaweed can be obtained by drying in air oven at a temperature of 120^{o}C, in order to obtain constant weight. Found it had an initial moisture content of 94.6%.

The values of the coefficient of determination (R^2), mean bias error (MBE) and root mean square error (RMSE) are used to determine the quality of the drying model. The highest R^2 values and the values of MBE and the lowest RMSE are selected to estimate the drying curve is the best (Ibrahim et al. 2009).

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

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

III. Results and Discussion

The results of the test results of kinetic curves of drying seaweed at 40, 50 and 60^{o}C, and the relative humidity of 10, 25 and 40% are shown in Fig. 2 to Fig. 11. It consists of three curves of the drying curve, the drying rate curve and the characteristic drying curve. Drying curve shows the profile change in moisture content (X) versus drying time (t). Drying rate curve shows the drying rate profile (dX/dt) versus drying time (t). Drying characteristic curves showed that the drying rate profile (dX/dt) versus moisture content dry basis (X).

Fig. 2 shows a decrease in moisture content wet basis of drying time at 10% relative humidity. Fig. 3 to Fig. 5 shows the curves of the moisture content dry basis of seaweed on the temperature and relative humidity vary. From these graphs, that the lower drying temperature and relative humidity large, increasing the moisture content of seaweed and cause slow down the drying time becomes longer. In contrast to the higher drying temperatures and low relative humidity the moisture content will be rapidly reduced.

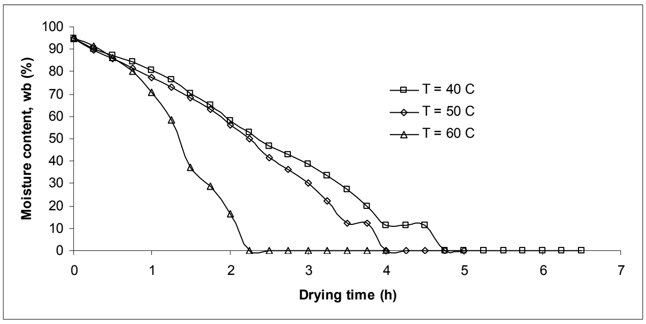

Fig.2. Moisture content variation with drying time at 10% RH

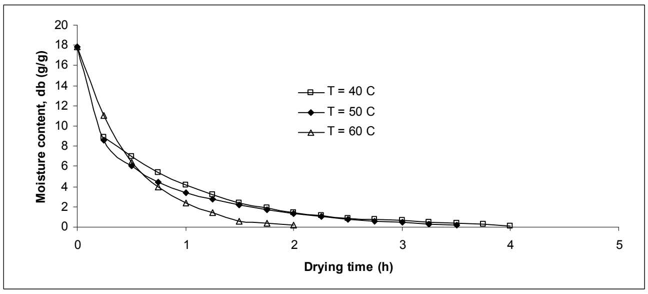

Fig. 3. Drying curve: dry basis moisture content versus drying time at 10% RH

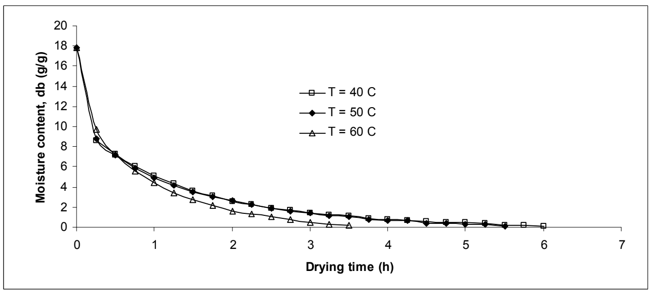

Fig. 4. Drying curve: dry basis moisture content versus drying time at 25% RH

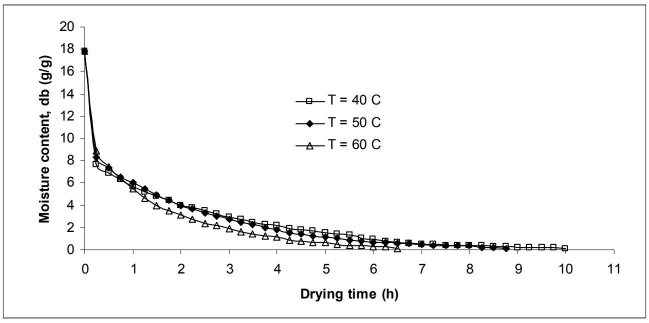

Fig. 5. Drying curve: dry basis moisture content versus drying time at 40% RH

Fig. 6 to Fig. 8 shows the profile of the drying rate versus drying time. From these graphs, the drying rate was found higher in the high drying temperature and relative humidity is low. This means that the time required to dry the material to reach equilibrium moisture content is shorter. The higher the drying temperature and relative humidity, the lower the higher the rate of evaporation of water from the material, this happens because the higher temperatures and low relative humidity vapor pressure of pure water would be higher, so the difference in partial pressure of water vapor with a vapor pressure of pure water is great. Pure water vapor pressure difference of partial pressure of water vapor at the appropriate temperature is the driving force for the water evaporates into the air. The greater the driving force will be greater the rate of evaporation of water into the air (Yahya 2007)

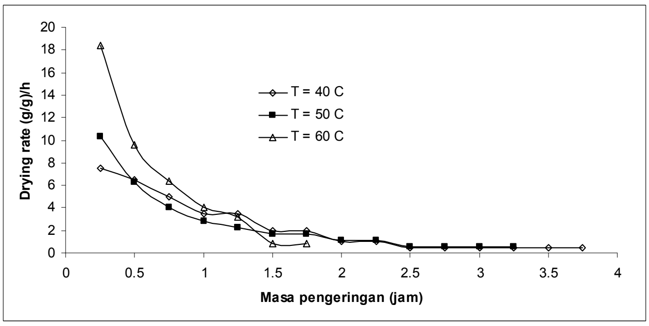

Fig. 6. Drying rate curves: dry basis moisture content versus drying time at 10% RH

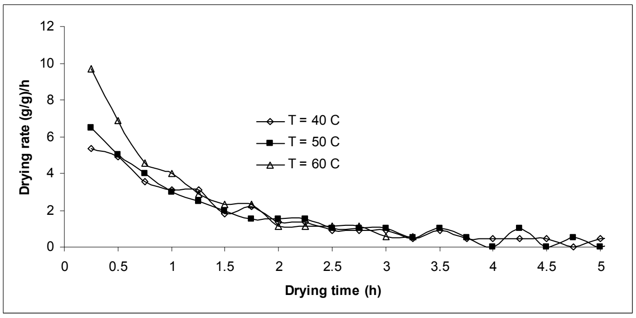

Fig. 7. Drying rate curves: dry basis moisture content versus drying time at 25% RH

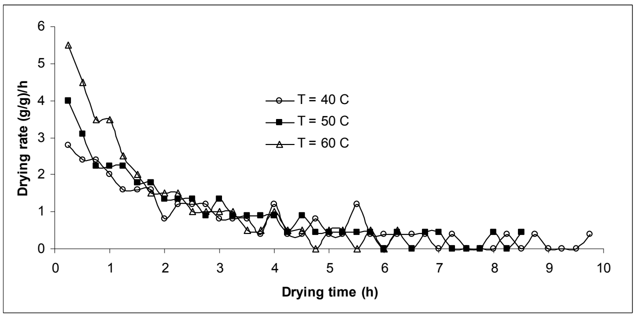

Fig. 8. Drying rate curves: dry basis moisture content versus drying time at 40% RH

Fig. 9 to Fig. 11 show the characteristic drying curve obtained at the temperature and relative humidity are different. These curves show that the adjustment and the constant drying rate can not be drawn with the real because the levels have a very short time. This proves that the drying seaweed according to the method of drying food ingredients and substances from plants in general, the constant rate period is very short.

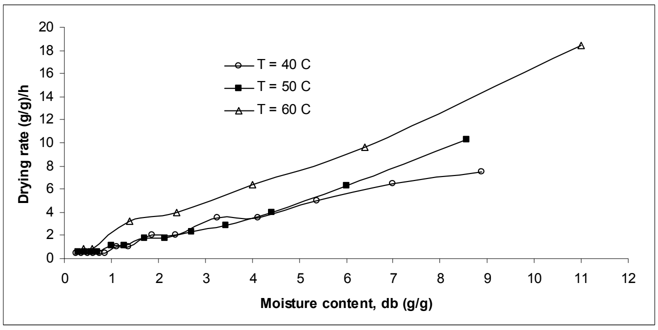

Fig. 9. Drying characteristic curves: a dry basis moisture content versus drying time at 10% RH

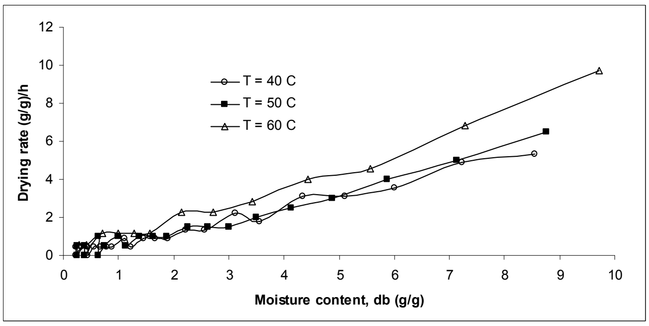

Fig. 10. Drying characteristic curves: a dry basis moisture content versus drying time at 25% RH

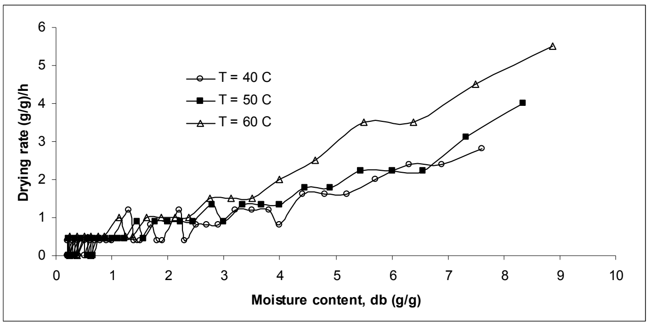

Fig. 11. Drying characteristic curves: a dry basis moisture content versus drying time at 40% RH

Fitting some of the drying model has been done with the experimental data of drying seaweed at 40, 50 and 60°C and relative humidity 10, 25 and 40%. Drying models are fitted with the experimental data of drying is the drying of 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 this drying models, changes in moisture content versus time calculated using Excel software, and constants calculated by graphical method. The result fitted the drying models with experimental data of drying are listed in Table 2 to Table 4. From the Tables are shown constant drying and precision fit each model of drying. R^2 is the highest and the MBE and the lowest RMSE is selected to estimate the drying curve is the best (Ibrahim et al. 2009). Page equation can also be written to the 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. 13. Henderson and Pabis equation can also be written by 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. 14, obtained the value k = 2.5378 and the value of a = 1.2327

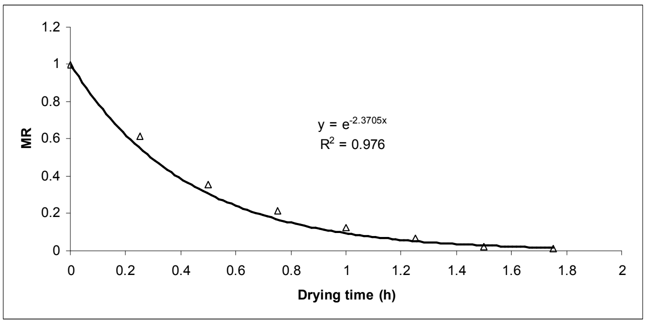

Fig. 12. Plot of MR versus drying time (Newton's model) at 10% RH and temperature 60°C

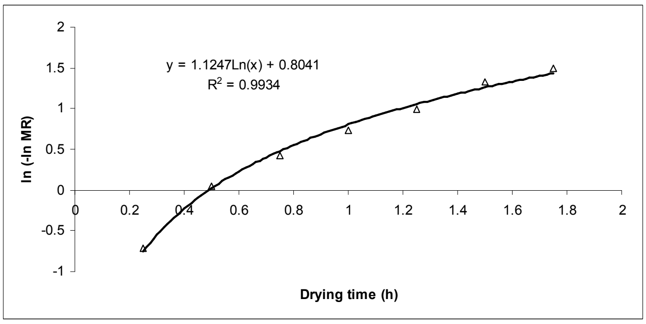

Fig. 13. Plot of ln (-ln MR) versus drying time (Page's model) at 10% RH and temperature 60°C

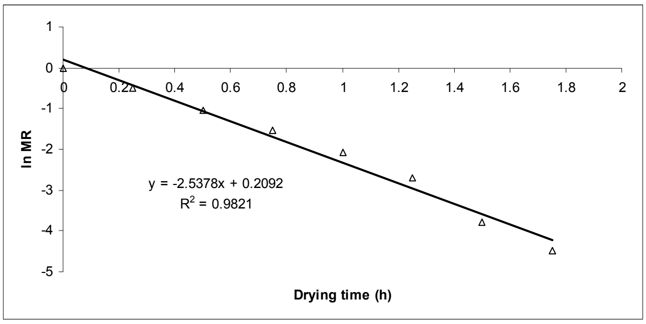

Fig. 14. Plot of ln MR versus drying time (Henderson and Pabis model) at 10% RH and temperature 60°C

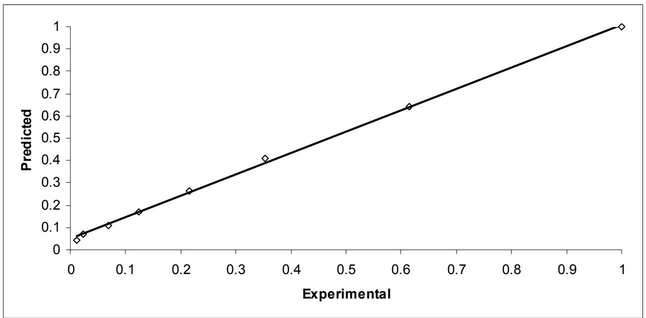

Fig.15. Comparison of experimental MR with predicted MR from Newton model, at 10% RH and temperature 60°C

Fig.16. Comparison of experimental MR with predicted MR from Page model, at 10% RH and temperature 60°C

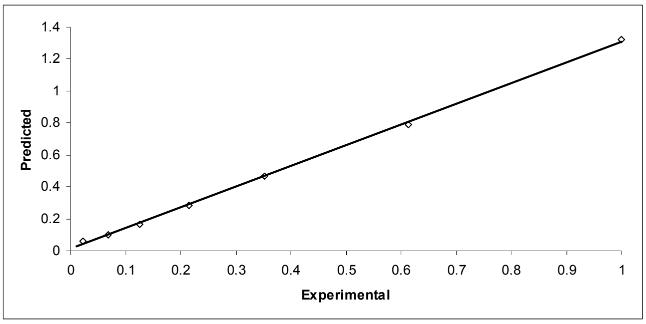

Fig.17. Comparison of experimental MR with predicted MR from Henderson and Pabis model, at 10% RH and temperature 60°C

Results are given in Table 2 to Table 4 shows the Page drying model has the highest value of R^2, as well as the values of MBE and RMSE is the lowest compared to Newton's model and Henderson and Pabis model, so seaweed drying model is a model suitable drying Page.

Table 2. Constants value fitting of Newton model

RH (%)	T (°C)	k	R2	MBE	RMSE
10	40	1.2678	0.9776	0.0106	0.1031
	50	1.7503	0.8103	0.0238	0.1543
	60	2.3705	0.9760	0.0017	0.0008
25	40	1.0685	0.7713	0.0051	0.0717
	50	0.9290	0.9639	0.0094	0.0967
	60	1.7754	0.8127	0.0024	0.0012
40	40	0.5355	0.9038	0.0166	0.1287
	50	0.6635	0.7622	0.0102	0.1008
	60	0.7748	0.9599	0.0106	0.1030
			0.8820	0.0100	0.0845

Table 3. Constants value fitting of Page model

RH (%)	T (°C)	n	k	R^2	MBE	RMSE
10	40	0.7297	1.6154	0.9806	0.0020	0.0443
	50	0.8358	1.8236	0.8891	0.0029	0.0537
	60	1.1247	2.2347	0.9934	0.0043	0.0022
25	40	0.7562	1.3406	0.8606	0.0013	0.0360
	50	0.6577	1.3932	0.9571	0.0006	0.0025
	60	0.9556	1.5987	0.8890	0.0015	0.0008
40	40	0.5061	1.1905	0.9130	0.0010	0.0313
	50	0.6494	1.1192	0.8569	0.0016	0.0404
	60	0.6352	1.2730	0.9559	0.0006	0.0254
				0.9217	0.0018	0.0263

Table 4. Constants value fitting of Henderson and Pabis model

RH (%)	T (°C)	k	a	R^2	MBE	RMSE
10	40	1.1630	0.7630	0.9886	0.0666	0.2581
	50	1.9077	1.5018	0.8179	0.0120	0.1097
	60	2.5378	1.2327	0.9821	0.2815	0.1407
25	40	1.1591	1.4922	0.7778	0.0351	0.1874
	50	0.8417	0.7313	0.9783	0.0045	0.0669
	60	2.0635	2.2082	0.8351	0.1322	0.0661
40	40	0.4348	0.5798	0.9744	0.0052	0.0721
	50	0.6669	1.0206	0.7623	0.0111	0.1053
	60	0.6902	0.6982	0.9800	0.0044	0.0666
				0.8996	0.0614	0.1192

IV. Conclusion

Drying using a Low Temperature and Humidity Chamber Test is tested on samples of seaweed. Drying kinetics curves of drying seaweed have known. Seaweed drying time is affected by temperature and humidity of the drying air. Constant rate period of drying seaweed is very short and not apparent in the characteristic drying curve. Drying at 60°C and relative humidity of 10% is the best way to seaweed, with the appropriate equations are equations with the Page model drying equation $MR = \exp(-2.23474t^{1.1247})$ with 99.3% accuracy. Overall, the Page model better than Newton's model and Henderson and Pabis model. It can be seen from the average values of the highest R^2 and the average values of MBE and RMSE is the lowest. The higher drying temperatures and low relative humidity the moisture content will be rapidly reduced.

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