Mathematical Modelling of Brown Seaweed Drying Curves

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Abstract: - Simple solution on one-term exponential models 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 Newton model, Page model, and Henderson and Pabis model compared with experiment data seaweed drying at 40, 50 and 60°C and relative humidity 10, 25 and 40%. The goodness or the quality of the fit is determined by fitting the highest the values of the coefficient of determination (R^2), and mean bias error (MBE) and root mean square error (RMSE) values are the lowest. The Page model is showed a better fit to drying brown seaweed among other models.

Keywords: - Mathematical models, drying curves, brown seaweed

1. Introduction

Eucheuma cottonii is a type of brown seaweed, which is one source of income, particularly people in Semporna, Sabah, Malaysia. The seaweed industry is grown but it is also become a source of income if carried out by communities, associations as well as individuals. Seaweed is widely used in production of food and medical products and industry manufacture at present [1]. Ge et al. [2] reported brown seaweed *Laminaria japonica* can be used for the production of alginate, iodine and mannitol. They reported that seaweed excellent prospects as a potential feedstock for the production of bioethanol. Seaweed as an energy resource to produce biogas has been studied by Vergara-Fernandez et al.[3].

Malaysia is a country that exports many agricultural and marine products to other countries. Demand for products of agriculture and marine products is a high quality dry. Most agricultural commodities and marine products require drying process in an effort to finally get a quality product [4]. Air drying is the most frequently used dehydration operation in the food and chemical industry. 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 [5].

Recently, many researches on experimental studies and mathematical modeling have been widely and effectively used for analysis. Thin-layer drying models have been used for analysis of drying of various marine and agricultural products. 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 is to propose mathematical model for the drying curves of brown seaweed (*Eucheuma cottonii*).

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Nomenclature

a	drying constant
d	mass of dry materials
exp	exponential
RH	relative humidity (%)
k	drying constant
M	moisture content
Me	equilibrium moisture content
Mo	initial moisture content
MBE	mean bias error
N	number of observations
n	drying constant
R^2	coefficient of determination
RMSE	root mean square error
T	temperature (^{o}C)
t	drying time
w	mass of wet materials

2. Material and Methods

Fig. 1 shows photograph Constant Temperature and Humidity Chamber Test (Model DY110, Angelantoni Asean Pte Ltd, Singapore) in the Solar Energy Laboratory of the Faculty of Science and Technology Universiti Kebangsaan Malaysia. Temperature and humidity range are -40 to 180^{o}C and 10 to 98% RH, respectively. 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^{o}C), and three relative humidity (10, 25 and 40% RH) are applied. Air velocity is kept constant at 1 m/s for all experiments.

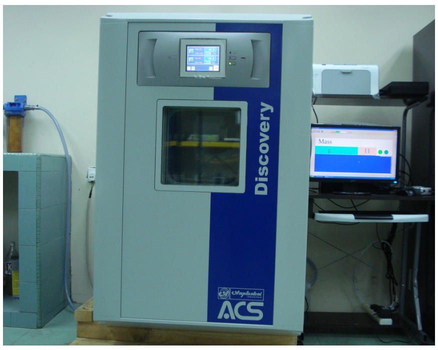

Fig. 1 photograph Constant Temperature and Humidity Chamber Test

Fig. 2 shows photograph an air oven and an analytical balance digital are used to determine the initial moisture content. Initial moisture content of brown seaweed can be obtained by drying in air oven at a temperature of 120^{o}C, in order to obtain constant weight. From tests with seaweed drying air oven found it had an initial moisture content of 91.58%.

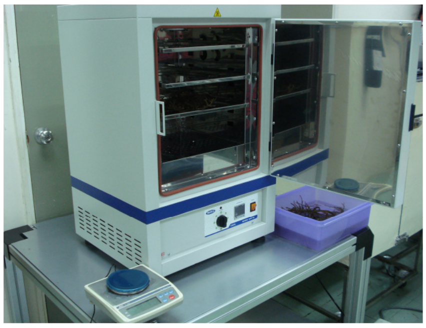

Fig. 2 photograph an air oven, an analytical balance digital and brown seaweed

Brown 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^{o}C to 60^{o}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 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 [6]

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

The moisture content dry basis

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

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 [7]

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

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

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

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.

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

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

3. Results and Discussion

Fig. 3 shows a decrease in moisture content wet basis of drying time at 10% relative humidity. Fig. 4 to Fig. 6 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.

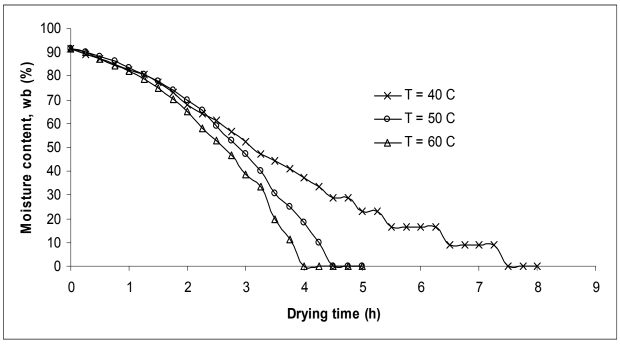

Fig.3 moisture content variation with drying time at 10% RH

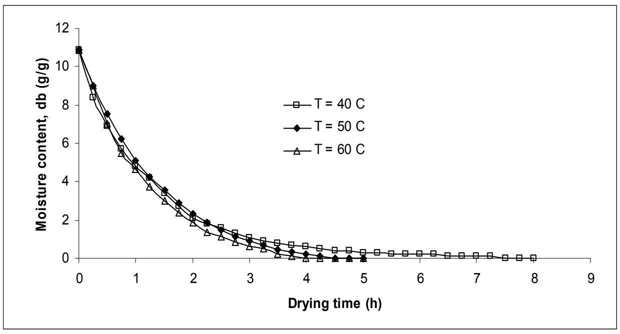

Fig. 4 drying curve: dry basis moisture content versus drying time at 10% RH

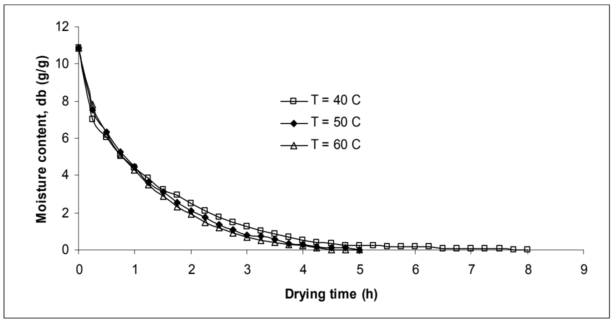

Fig. 5 drying curve: dry basis moisture content versus drying time at 25% RH

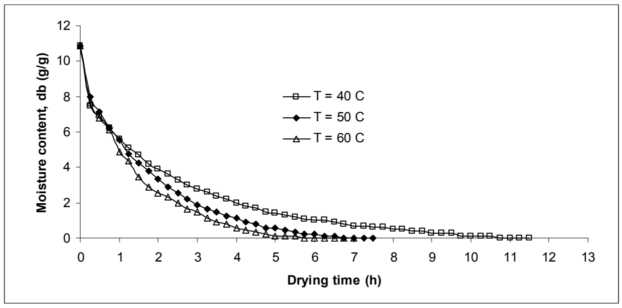

Fig. 6 drying curve: dry basis moisture content versus drying time at 40% RH

Fitting some of the drying model has been done with the experimental data of drying seaweed at 40, 50 and 60^{o}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.

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. 8.

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. 9, obtained the value k = 1.1241 and the value of a = 1.2506.

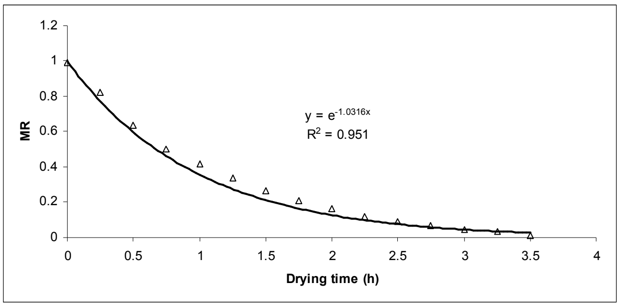

Fig. 7 plot of MR versus drying time (Newton's model) at 10% RH and temperature 60°C

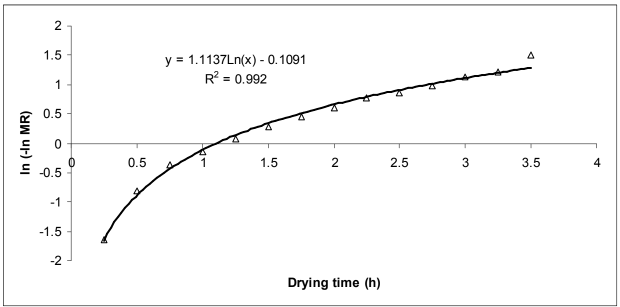

Fig. 8 plot of ln (-ln MR) versus drying time (Page's model) at 10% RH and temperature 60°C

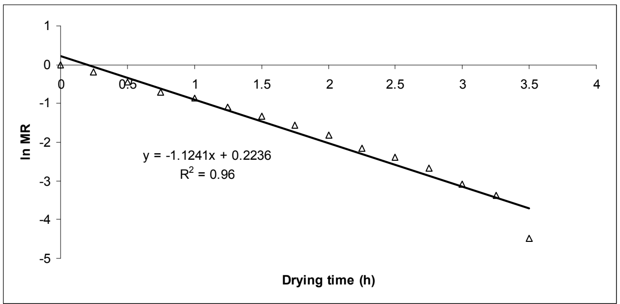

Fig. 9 plot of ln MR versus drying time (Henderson and Pabis model) at 10% RH and temperature 60°C

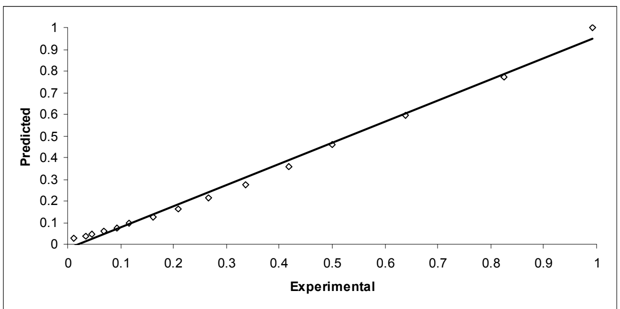

Fig.10 comparison of experimental MR with predicted MR from Newton model, at 10% RH and T = 60°C

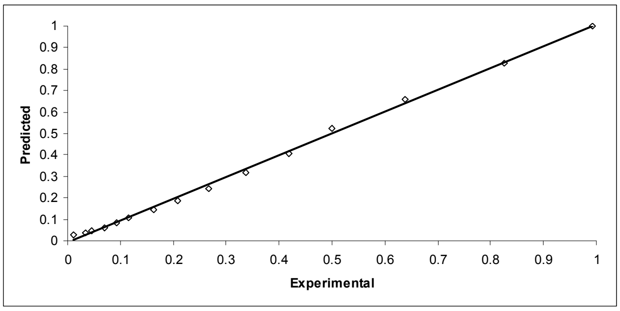

Fig.11 comparison of experimental MR with predicted MR from Page model, at 10% RH and T = 60°C

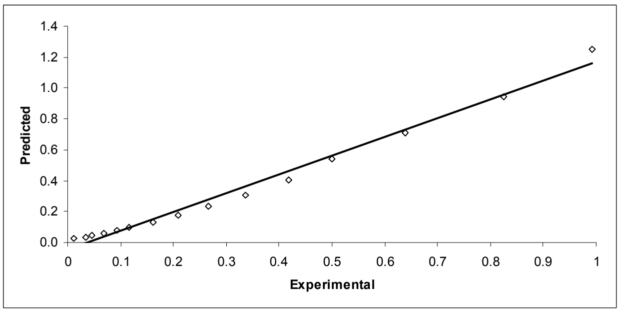

Fig.12 comparison of experimental MR with predicted MR from Henderson and Pabis model, at 10% RH and T = 60°C

Results are given in Table 2 to Table 4 shows the Page 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 brown seaweed drying model is a model suitable drying Page.

Table 2. Constants value fitting of Newton model

RH (%)	T (°C)	k	R^2	MBE	RMSE
10	40	0.7872	0.9944	0.000270	0.016425
	50	0.9425	0.9513	0.002197	0.046870
	60	1.0316	0.9510	0.001377	0.037112
25	40	0.8098	0.9883	0.001797	0.042395
	50	0.9495	0.9661	0.000957	0.030934
	60	1.0133	0.9743	0.000747	0.027334
40	40	0.4191	0.9825	0.004706	0.068597
	50	0.6672	0.9642	0.001106	0.033253
	60	0.7986	0.9623	0.000887	0.029779
Average			0.9705	0.001560	0.036967

Table 3. Constants value fitting of Page model

RH (%)	T (°C)	n	k	R^2	MBE	RMSE
10	40	0.9317	0.8626	0.9969	0.000097	0.009868
	50	1.1192	0.7899	0.9902	0.000281	0.016766
	60	1.1137	0.8966	0.9920	0.000212	0.014546
25	40	0.8336	0.9884	0.9677	0.000798	0.028248
	50	0.9013	1.0003	0.9713	0.000644	0.025378
	60	0.9355	1.0329	0.9807	0.000500	0.022350
40	40	0.7113	0.6973	0.9750	0.000535	0.023133
	50	0.8774	0.7471	0.9674	0.000765	0.027650
	60	0.8937	0.8587	0.9710	0.000639	0.025281
Average				0.9791	0.000497	0.021469

Table 4. Constants value fitting of Henderson and Pabis model

RH (%)	T (°C)	a	k	R^2	MBE	RMSE
10	40	0.9511	0.7754	0.9947	0.000148	0.012156
	50	1.3367	1.048	0.9648	0.009755	0.098769
	60	1.2506	1.1241	0.9600	0.005961	0.077210
25	40	0.9853	0.8063	0.9884	0.001580	0.039755
	50	1.1304	0.9915	0.9684	0.003663	0.060520
	60	1.1378	1.0602	0.9769	0.003610	0.060082
40	40	0.8061	0.3855	0.9927	0.001227	0.035026
	50	1.1249	0.6961	0.9665	0.003815	0.061765
	60	1.1104	0.8308	0.9643	0.002910	0.053947
average				0.9752	0.003630	0.055470

4. Conclusion

Drying using a Constant Temperature and Humidity Chamber Test is tested on samples of brown seaweed. Drying kinetics curves of drying brown seaweed have known. Overall, the Page's model is showed a better fit to the experimental data among other models. It can be seen from the average values of the highest R^2 and the average values of MBE and RMSE is the lowest.

Acknowledgements

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