Modified Page Model for Solar Drying of Seaweed

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Abstract

This study aimed to determine the appropriate model for solar drying of seaweed. In this study, solar drying of seaweed was conducted at an average air temperature of approximately 50 °C and a mass flow rate of approximately 0.054 kg/s. After 15 h of solar drying with a relative humidity of 43%, water loss of 84% was observed. The data were analysed and recorded to determine the best model for solar drying using the values of the coefficient of determination (R2), mean bias error and root mean square error. The nonlinear regression method was used in this study. The modified Page model was compared with three thin-layer drying models presented in previous studies.

Keywords: Solar energy, drying kinetics, thin layer drying, drying curve

1. Introduction

Two types of energy, namely, renewable and non-renewable, exist on earth. The sources of non-renewable energy cannot be replaced in a short time, whereas the sources of renewable energy are available continuously. Among the energy sources that cannot be replenished are coal, petroleum and gas. Meanwhile, renewable energy sources are solar energy, wind energy, hydropower and biomass fuels. Supplies and fossil energy reserves are currently limited. The use of conventional energy sources is harmful because fossil energy is decreasing and will run out someday. Thus, this generation will be heavily dependent on renewable energy sources. Solar energy is one of the alternative energy sources that are used widely and is currently used as a primary energy source in many countries in the world. The use of solar energy is cheap and economical and does not pollute the environment. Over the centuries, humans have been using this energy source for drying agricultural products, medicines and herbs. They use this energy source in a primitive manner, which requires a broad area and is prone to environmental pollution [1-10].

Solar energy has long been used by people to dry clothes, salted fish and agricultural products. The conventional practice of drying directly under the sun is known to be safe. Most agricultural and fishery commodities also require a drying process to obtain the final product. Among these commodities are cocoa, coffee, rubber, pepper, tobacco, tea, bananas, anchovies and seaweed. Various types of solar drying systems have been used to dry agricultural and fishery products around the world. The solar energy industry has also been used since time immemorial to dry plants, seaweed and herbs. In Malaysia, a solar-assisted drying system consisting of two collector lines with a finned absorber plate and solar collectors is one alternative in the development of technology and research to achieve high collection efficiency [11–19].

Malaysia is a country located in the temperate equatorial latitude 1°20′–6°40′ North and longitude 99°35′–103°20′ East with an average solar radiation between 400 and 700 W/m^2. Radiant energy in Malaysia is relatively high, and thus the potential for the development and enhanced use of solar energy is also high. This energy will be wasted if it is not used to its maximum potential. Agricultural agencies, such as MARDI and FRIM, and various universities have conducted studies to promote the use of solar energy in the future. The government has produced a solar drying system with the objective of helping people in their everyday lives and in drying agricultural and fishery products. Although the dryer system requires high construction costs, it has several advantages as follows: (i) the drying temperature can be controlled and set appropriately, (ii) its space and capacity are large, (iii) the system is independent of the weather and (iv) drying time can be reduced by 50% compared with conventional practice [11-19].

The solar drying of palm oil fronds [20] salted silver jewfish [21], red chili [22], seaweed [23], and agricultural products in Malaysia was evaluated. Various studies on the drying kinetics and thin-layer drying models for marine products, fruits and vegetables [24,25] were conducted. The drying kinetics of brown seaweed at different temperatures was investigated, and the results were used to calculate the diffusion coefficients [26]. The drying kinetics of agricultural and marine products can also be accurately predicted using Newton's model, Page's model and Henderson and Pabis' model. In the present study, the modified Page model was compared with three models presented in previous studies.

2. Materials and Methods

Samples of red seaweed (*Gracilaria changii*), also known as '*rumpai laut merah*', were obtained from Kedah, Malaysia. A solar dryer was installed in the Green Energy Technology Innovation Park, Universiti Kebangsaan

Malaysia (UKM), as shown in Fig. 1. The solar dryer was classified as indirect-type forced convection. The system consisted of a finned double-pass solar air heater, an auxiliary heater, a blower and a drying chamber. Four solar air heaters were set within a total area of 11.52 m^2. The drying chamber dimensions were 4.8 m long, 1 m wide and 0.6 m high.

This study investigated the drying process of seaweed in the UKM using a solar dryer with two collector lines and a finned absorber plate. The drying process takes approximately 15 h to reduce the initial moisture content of 94% to a final moisture content of 10%. This value is equivalent to the 120 g initial mass of the material to a final mass of 17 g. The drying process occurs at a mass flow rate of 0.05 kg/s and an average temperature of 50 °C. Changes in the mass of the material were recorded every 30 min. The seaweed drying data were fitted using the modified Page model expressed in Eq. (1), and the moisture ratio (MR) was calculated using Eq. (2), as follows:

$$MR = \exp\left(-(kt)^n\right) \quad (1)$$

and

$$MR = \frac{M - M_e}{M_0 - M_e}, \quad (2)$$

where M_0 is the initial moisture content and Me is the equilibrium moisture content.

The values of root mean square error (RMSE), mean bias error (MBE) and coefficient of determination (R^2) were used to determine the quality of the drying model. The lowest RMSE value and the highest R^2 value were selected to estimate the best drying curve [22-25]:

$$MBE = \frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{\exp,i}\right)^2 \quad (3)$$

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

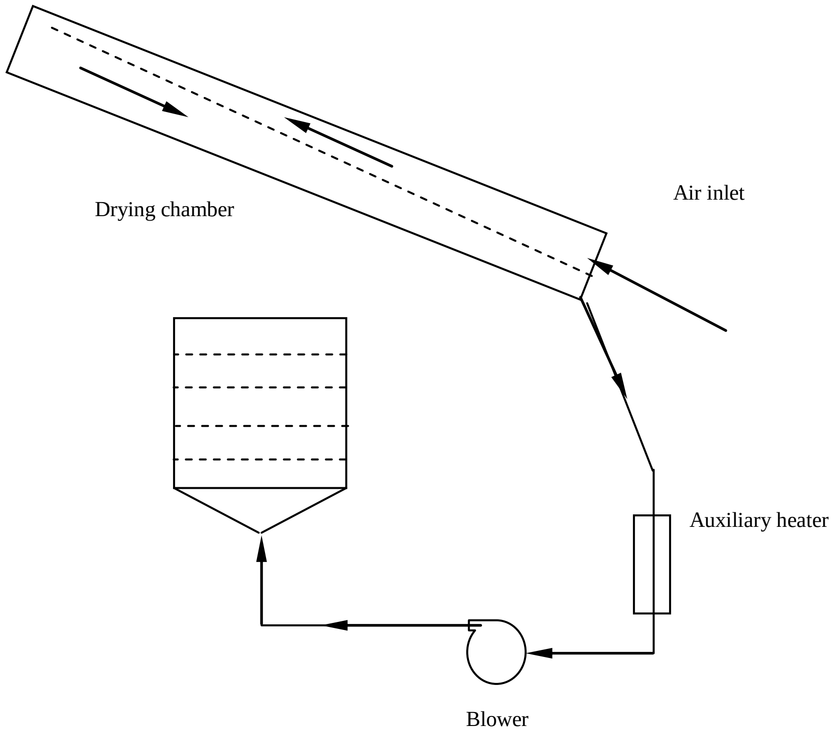

Figure 1. Schematic of the Solar Dryer

3. Results and Discussion

The results of the experiment showed that the moisture content of seaweed decreased from 90% to 10% after 15 h of drying at a temperature of 50 °C with a relative humidity of 43%. The drying model was fitted with the drying data in the form of changes in moisture content versus drying time and was calculated using Excel software. Fitting of the modified Page model was conducted using the experiment data, as shown in Fig. 2. The modified Page equation [Eq. (1)] can also be written in the following forms:

$$\ln(-\ln MR) = n \ln k + n \ln t, \quad (5)$$

$$y = A + B \ln t, \quad (6)$$

where:

$$A = n \ln k, \quad (7)$$

$$B = n, \quad (8)$$

$$k = \exp(A/B). \quad (9)$$

Eq. (5) shows the correlation ln(−ln MR) with drying time. Fig. 2 shows the curve of the logarithmic equation. Moreover, the figure clearly shows that the value of the constant *n* was 0.6123 and the obtained value of the constant *k* was 0.9105.

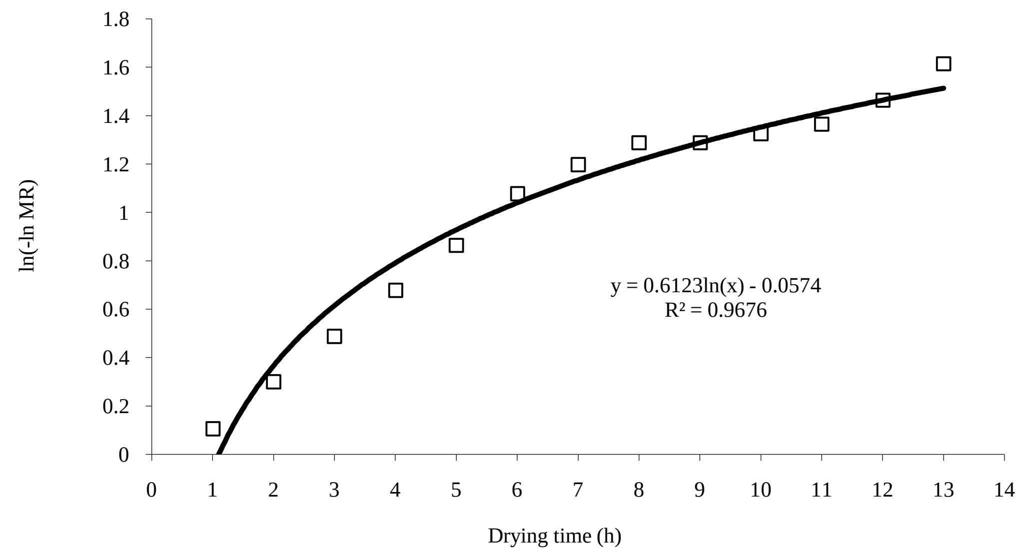

Figure 2. Modified Page Model: Plot of Ln(−Ln MR) versus Drying Time

Table 1. Results of the Nonlinear Regression Analysis [23]

Model	*k*	*a*	*n*	MBE	RMSE	R^2
Newton	0.4019			0.00529	0.07274	0.9033
Henderson and Pabis	0.3327	0.5367		0.00685	0.08275	0.9608
Page	0.9442		0.6123	0.00023	0.01510	0.9676
Modified Page*	0.9105		0.6123	0.00024	0.01539	0.9676

4. Conclusion

The results of solar drying of red seaweed (G. *changii*) showed that the modified Page model exhibited the best fit with respect to the values of R^2 (0.9676), MBE (0.00024) and RMSE (0.01539). The modified Page model could likewise be used to predict the precise moisture content of dried seaweed after solar drying.

Acknowledgments

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