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# Cubic Spline as a Powerful Tools for Processing Experimental Drying Rate Data of Seaweed Using Solar Drier

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## ABSTRACT

A solar drying experiment of seaweed, *Kappaphycus alvarezii* var. *tambalang* using v-groove hybrid solar drier (v-GHSD) was conducted in Semporna, Sabah, under the meteorological condition of Malaysia. Drying of the seaweed in the v-GHSD led to a reduction in its moisture content from 85.32% to 38% in 5 days with mean solar radiation of 650 W $m^{-2}$ and mass flow rate of approximately 0.27 kg $s^{-1}$. Generally, the plots of the drying rate required more smoothing compared to the moisture content data; special care was needed at low drying rates and moisture contents. Here, we show that the cubic spline (CS) can be effective for estimating the drying rate-time curves. The idea of this method consists of an approximation of data by a CS regression having first and second derivatives. The analytical differentiation of the spline regression permitted the determination of instantaneous rate. The method of minimizing the function of average risk was used successfully to solve the problem. This method allowed us to obtain the instantaneous rate directly from the experimental data. Mathematical models using the raw data tested with the smoothed CS were found to be reliable estimators of the moisture-time curves as well as for the missing moisture content data of the seaweed.

**Keywords:** Mathematical modeling, solar drying, drying curve, rate data, smoothing, moisture content, cubic spline, seaweed *Kappaphycus alvarezii* var. *tambalang*.

# 1. Introduction

Drying methods play an important role in the preservation of agricultural products (see Ali et al. (2013)). Air drying is the most frequently used dehydration approach in the food industry (see Ali et al. (2014a), Ali et al. (2015)). The main concerns pertinent to the production of dried foods in in meeting quality specifications and in conservation of energy, which emphasizes the need for a thorough understanding of the drying process.

Seaweed is widely used in fabrication of food and medicines. It also has the potential for being a source of renewable energy as raw material for biofuel. According to Dissa et al. (2011), seaweed is currently mainly produced for its carrageenan. Carrageenan is used as in various food and non-food industries such as in pet food production and cosmetics (Ali et al. (2015)). Meanwhile, the East ASEAN Growth Area reported that the world demand of carrageenan from seaweeds is expected to increase up to 80% by the year 2020 in Hurtado et al. (2014) . Seaweed is becoming an important agricultural crop in Malaysia, which prompted the Malaysian Government to allocate RM 58.87 million to boost this sector in 2011 (Fudholi et al. (2012)). Moreover, there have been strategies and incentives put in place under the Third Economic Transformation Programme (3ETP), such as the Algae Farming via Mini Estate System in Sabah (Ali et al. (2014c)), Seaweed Identification Grant, Seaweed Cultivation Grant, and funding from the National Key Economic Area (NKEA). Seaweed has garnered more attention because of its high of nutritional value (see Midilli and Kucuk (2003)) and fast turnover rate that is only 45 days per cycle (Ali et al., 2014b).

The conventional hanging method has been widely used in seaweed production. The method requires a large, open area, which can be a limiting factor, and the production is susceptible to changing weather conditions, which may lead to longer drying time, decreased product quality, and contamination (Ratti and Mujumdar (1997)). Several experimental and theoretical studies have reported on the development of various types of solar drying systems for agricultural and marine products in Midilli et al. (2002). Concurrently, many experimental studies and mathematical models have been applied to analyze the efficiency of these methods in Ahlberg et al. (1967), Tripathy and Kumar (2009) and Yasir (2013).

Although numerous mathematical models have been proposed to describe the drying process, very few have been done regarding solar-drying behaviors and in addition, none have employed smoothing using the cubic spline (CS) method. According to Ali et al. (2014d), CS is the most effective method for estimating moisture-time drying rate and in this study, we demonstrated the implementation of CS for smoothing the drying rate of moisture-time curve in seaweed dried using v-groove hybrid solar drier (v-GHSD).

## 2. Materials and Method

The seaweed *Kappaphycus alvarezii* var. *tambalang* used in this study were obtained from UMS Seaweed Mini Estate in Semporna, Sabah. The initial moisture content of the seaweed was determined by measuring its initial and final weight, $I$, which the latter was obtained by drying the samples in an oven at 115°C in order to obtain the dry weight inAOA. The average initial moisture content of the samples was 95.68%.

Figure 1: *Kappaphycus alvarezii* var. *tambalang*

A v-GHSD was installed at Selakan Island, Semporna. The drier is classified as a forced convection indirect type. The solar drier unit consists of fans, drying chamber, v-aluminum roof, a solar collector, and trays with Teflon screen tape (Figure 2). The highest recorded relative humidity (% RH) of the drier was 80% and the maximum temperature inside the drier that was recorded is 60°C (Figure 3). The maximum capacity of the drier is 5 tons.

Figure 2: Simulation diagram of v-GHSD

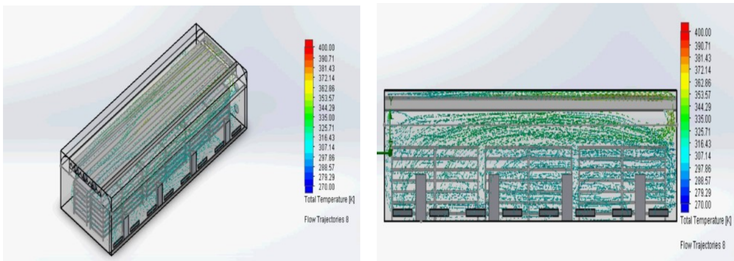


Figure 3: CFD Simulation diagram of v-GHSD

Data collection was done daily from 0800 until 1700 hours from 8/4/2014 to 24/4/2014. A day before the experiment commenced, 5 tons fresh seaweed was harvested that comprised of seaweed cultivated in a single cycle (45 days). After determining the initial weight, the seaweed was dried through a sauna process for 2 d. The main objective of the sauna is to reduce the moisture content to 50%. The pre-drying data was also recorded for the drier for 2 d. The remaining seaweed weighing about 2.5 tons was spread on the trays with Teflon screen tape with same depth and surface area. The same amount of samples was placed on different sections of the tray. The purpose of doing this was to study the drying kinetics. During the drying experiment, the weather was sunny every day except on 21/4/2014 where heavy rain occurred. The parameters measured were the air temperature (ambient, air temperature at the inlet, at the outlet, and inside of the drier), radiation intensity, and wind velocity.

Relative humidity and temperature sensors were installed at the inlet, outlet, and in the middle of the drying chamber. A T-type thermocouple was also used to record the air temperature. Meanwhile, a hygrometer was used to collect data on ambient relative humidity and temperature and the intensity of solar radiation was measured using a pyranometer. Data was logged every 30 min. The moisture loss was determined by weighing the sampled on a digital balance having an accuracy of 0.01 g. The moisture content was expressed on a percentage wet weight basis and then converted to gram water per gram dry matter.

The moisture ratio (MR) can be calculated as

$$MR = \frac{M - M_e}{M_0 - M_e} \tag{1}$$

where $M_e$ and $M_0$ are equilibrium moisture content and initial moisture content, respectively. Whereas, the moisture content of material ($M$) can be calculated using the following equation (see Zainodin et al. (2011)).

$$M = \frac{w(t) - d}{w} \times 100\% \tag{2}$$

where $w(t)$ is the mass of wet materials at the instant $t$ and $d$ is the mass of dry materials.

For CS, we will only consider the natural condition. The procedure to form the CS model is as follows

$$S_k(x) = a_k + b_k + c_k x^2 + d_k x^3. \tag{3}$$

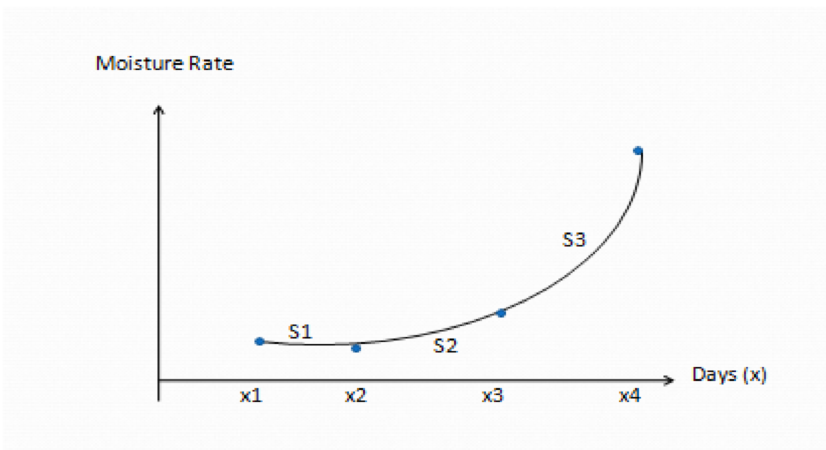


Figure 4: Moisture rate data versus number of days

**A** Functions of successive intervals must be equal at their **<u>common knot</u>**, $2(N-2)$ conditions

**B** The first and last functions must pass through the **<u>end knots</u>**, two conditions

**C** The $1^{st}$ and $2^{nd}$ derivatives of functions must be equal at their **<u>common knot</u>**, $2(N-2)$ conditions

**D** The $2^{nd}$ derivatives at the **<u>end knots</u>** are ZERO, two conditions.

For condition A

$$S_1(x_2) = a_1 + b_1x_2 + c_1x_2^2 + d_1x_2^3, \tag{4}$$

$$S_2(x_2) = a_2 + b_2x_2 + c_2x_2^2 + d_2x_2^3, \tag{5}$$

$$S_2(x_3) = a_2 + b_2x_3 + c_2x_3^2 + d_2x_3^3 \tag{6}$$

and

$$S_3(x_3) = a_3 + b_3x_3 + c_3x_3^2 + d_3x_3^3. \tag{7}$$

For condition B

$$S_1(x_1) = a_1 + b_1x_1 + c_1x_1^2 + d_1x_1^3 \tag{8}$$

and

$$S_3(x_4) = a_3 + b_3x_4 + c_3x_4^2 + d_3x_4^3. \tag{9}$$

For condition C

$$S_1^{'}(x_2) = b_1 + 2c_1x_2 + 3d_1x_2^2, \tag{10}$$

$$S_2^{'}(x_2) = b_2 + 2c_2x_2 + 3d_2x_2^2, \tag{11}$$

$$S_2^{'}(x_3) = b_2 + 2c_2x_3 + 3d_2x_3^2, \tag{12}$$

$$S_3^{'}(x_3) = b_3 + 2c_3x_3 + 3d_3x_3^2, \tag{13}$$

$$S_1'(x_2) = S_2'(x_2), \tag{14}$$

$$S_2'(x_3) = S_3'(x_3), \tag{15}$$

$$S_1''(x_2) = 2c_1 + 6d_1x_2, \tag{16}$$

$$S_2''(x_2) = 2c_2 + 6d_2x_2, \tag{17}$$

$$S_2''(x_3) = 2c_2 + 6d_2x_3, \tag{18}$$

$$S_3''(x_3) = 2c_3 + 6d_3x_3, \tag{19}$$

$$S_1''(x_2) = S_2''(x_2) \tag{20}$$

and

$$S_2''(x_3) = S_3''(x_3). \tag{21}$$

For condition D

$$S_1''(x_1) = 2c_1 + 6d_1x_1 \tag{22}$$

and

$$S_3''(x_4) = 2c_3 + 6d_3x_4. \tag{23}$$

# 3. Results and Discussions

Variations in the solar radiation, ambient temperature and relative humidity, and the drying chamber temperature and relative humidity are shown in Figure 5. The mean drying chamber temperature and relative humidity ranged from 30-64°C and 20-80%, respectively, while the intensity of solar radiation was between 150 and 1000 W $m^{-2}$ during the sixteen-days period.

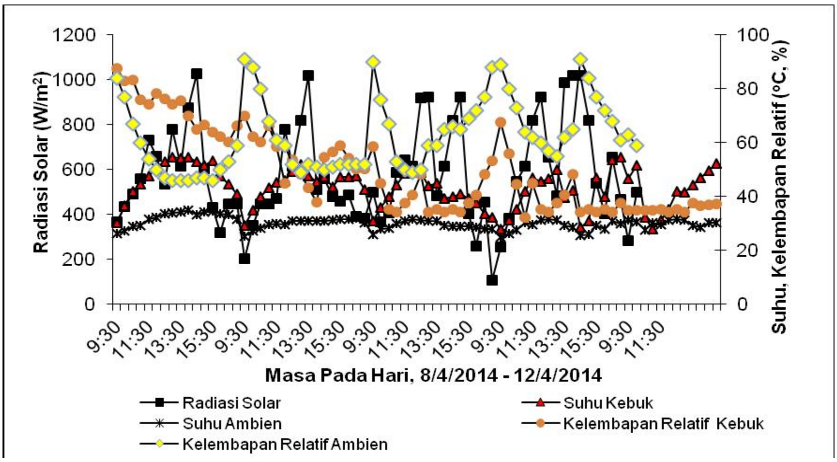


Figure 5: Temperature (chamber, ambient), relative humidity (chamber, ambient) and solar radiation versus time

During the fourth day of the experiment, the average temperature and relative humidity at the drying chamber was 50°C and 66%, respectively, while the mean solar radiation was 600 W $m^{-2}$. The total number of hours taken to dry the seaweed was 38 h through solar drying and 114 h through conventional drying.

The final mass of the seaweed was 250 kg. The final moisture content is about 38%, which is appropriate to the industry, as shown in Figures 6 and 7.

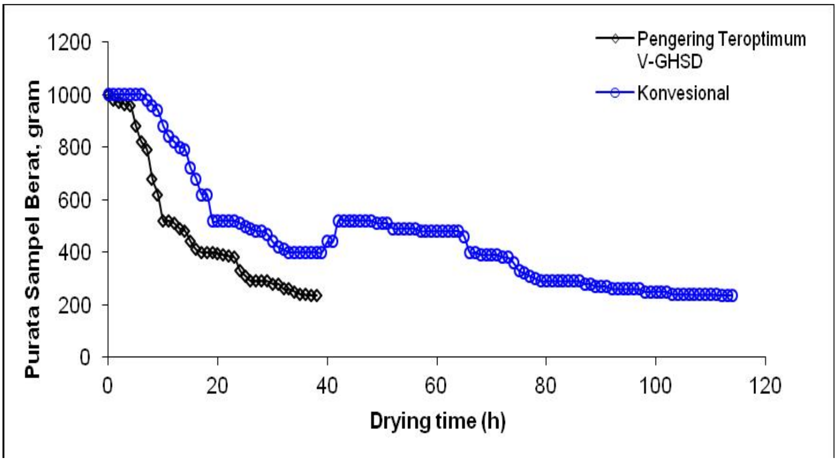


Figure 6: Moisture content versus time

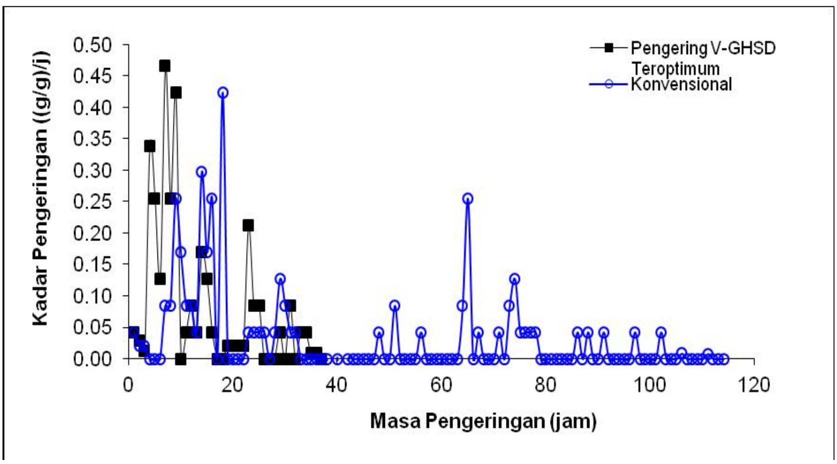


Figure 7: Comparison drying rate with drying time

There are a number of useful curves that are interrelated. For drying rate (refer Figures 7 and 8), they can be obtained by using differentiated moisture-content data. We also can estimate the drying rate from the humidity-time data. By using CS, we can smooth the drying rate data. The main purpose of CS is to make the drying rate reliable. Here, CS was formed by using $32 \times 32$ matrix. From the procedure that was discussed in Ahlberg et al. (1967), we can rearrange all sectors into matrices according to the conditions stated. The independent matrices have to then be inverted proportionally before they can be solved by multiplying the matrices with a dependent variable, $Y$. From the estimators of the coefficient of sector, we can then estimate the missing values corresponding to the drying rate of the seaweed. By using the estimators, we can also calculate back the drying rates and compare them with the raw drying rate data (smoothing). Based on Figures 9 and 10, it can be said that the CS is an effective method for smoothing the drying rate. The square errors for the graphs as illustrated in Figures 9 and 10 were $3.5445E-17$ and $6.30655E-17$, respectively.

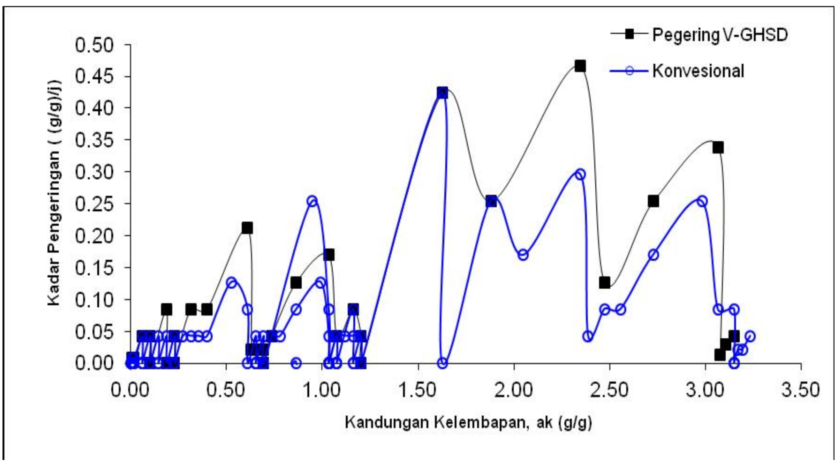


Figure 8: Comparison drying rate with moisture content

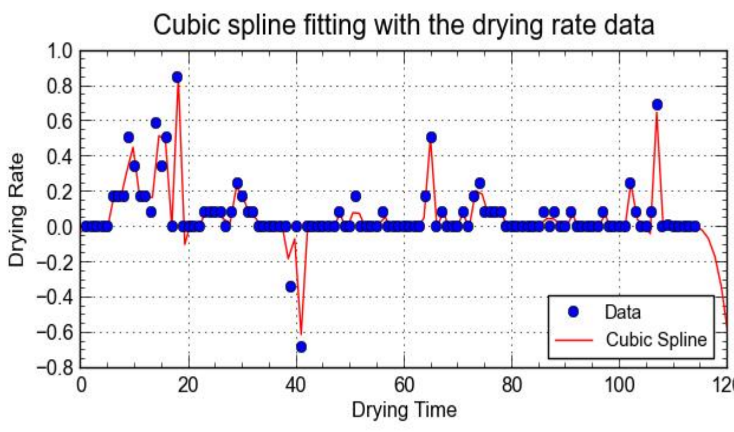


Figure 9: Smoothing by cubic spline of the drying rate through conventional drying

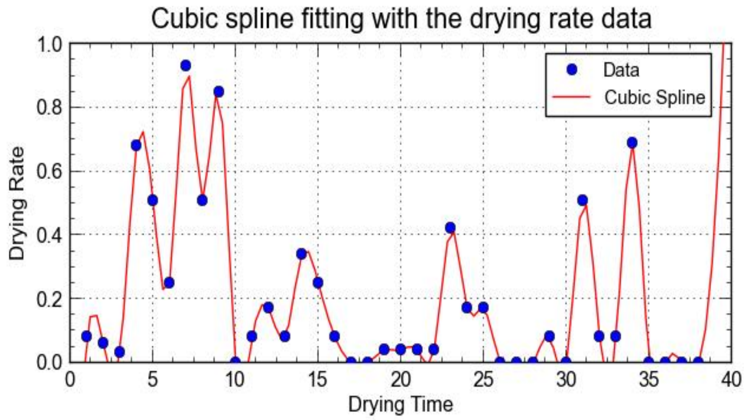


Figure 10: Smoothing by cubic spline of the drying rate through solar drying

# 4. Concluding Remarks

A solar drying system is tested on samples of seaweed, *Kappaphycus alvarezii* var. *tambalang*. Kinetics curves of the drying were known by using this system. Besides that, the cubic spline that was used to smooth the determined drying rates was shown to be effective for drying rate-tie curves. It is important to retain the original raw experimental data for cross checking, as smoothing can conceal valuable information.

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