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Performance study of hybrid solar dryer with auxiliary heater for seaweed drying

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Abstract. In this paper, the performance of hybrid solar dryer with auxiliary heater for seaweed drying is investigated. There were two drying modes performed, namely hybrid solar drying and conventional drying. The drying operation was done from 9.00 A.M until 1.00 P.M on each day, with the hybrid solar dryer temperature of 40, 50, and 60 °C. There were five analysis performed after the drying process was done. Experimental results showed that the dryer temperature, relative humidity, and solar radiation are highly dependent on the weather condition, drying time, and in the case of solar radiation, the geographical location. Drying curve analysis shown that drying at 60 °C gave the final moisture content of 12,2%, which satisfy the safe limit of dried seaweed product. Drying process is faster and most efficient during the early phase of drying. As drying process continues, the drying become less effective and the drying rate is gradually decreased until it reaches a constant value. Effectivity factor analysis shown that hybrid solar dryer is more effective than conventional drying. Color analysis result shows that to preserve the color quality of seaweed, it is better to perform the drying with the temperature of 50 °C.

1. Introduction

Seaweed is one of the most utilized marine commodities, mainly for human needs, such as for cosmetics or food products. This is because seaweed contains useful nutrients for humans, like vitamins, minerals, fat, amino acids, and antioxidant [1]. Seaweed is a natural source of fiber and often used as a raw materials for products like carrageenan, alginates, or jelly [2]. According to Demirbas [3], seaweed can also be converted to bio-oil, biodiesel, ethanol, methane, and hydrogen. Freshly harvested seaweed usually contains high moisture content (75-85%), therefore it would decomposed quickly if left in the open air for a long time. Hence, drying process is needed to halt the microbial growth and keep the seaweed's quality [4]. Generally, seaweeds are dried directly under the sun [4]. However, the product quality and the continuity of the process are highly dependant on weather. Besides, the seaweed is less hygiene due to the possible contaminations by animals, insects, and dusts [2]. Therefore, a solution is needed to solve those problems, one of them is solar dryer. Solar dryer is a drying method that utilizes



the solar radiation as the primary energy source, with a closed chamber to contain the material that need to be dried, therefore the dried materials will be protected from contaminations. This drying method is relatively cheap and easy to be applicated [5].

Some researchers have studied about seaweed drying. Gupta et al. [4] studied the effects of drying temperature to the moisture and the phytochemical constituents of Irish brown seaweed. They found that drying process reduced the phytochemical and phenolic contents of seaweed by 29% and 30%, respectively, when the seaweed is dried at 40 °C. Fudholi et al. [6] performed the energy and exergy analyses of solar drying system of red seaweed. They reported that after 15 hours of drying, the seaweed's moisture content was reduced from 90% to 10% wet basis, with the collector, drying, and exergy efficiency are 35%, 27%, and 30%, respectively. On the other hand, Sarbatly et al. [7] studied the kinetic and thermodynamic characteristics of seaweed dried in the convective air dryer. They found that the drying rate of seaweed is greatly affected by drying temperature, rather than the drying load or the air flow rate. Meanwhile, Ali et al. [8] studied the implications of drying temperature and humidity of the drying kinetics of seaweed, using a low temperature and humidity chamber. The reported that drying at 60 °C and with relative humidity of 20% gave the best results. They also found that Page model was the most suitable thin-layer drying model to describe the drying kinetics of seaweed.

Despite several advantages provided by the solar dryer, it still has weaknesses, such as long drying time and highly reliant on weather, just like conventional drying [9]. Therefore, a new development about new drying technology is required, so that the material may be dried to the allowable moisture content, according to the material's own standard. It is also needed to develop a new drying technology with faster drying time, more efficient, and does not depend on weather condition. In this paper, a new drying method is introduced, namely hybrid solar dryer. A solar dryer is equipped with LPG (Liquefied Petroleum Gas) as an auxiliary heater (hence the name is "hybrid" solar dryer) to increase the performance of solar dryer, as well as enabling the dryer to be operated during bad weather or during the night. The objective of this research are to study the drying curve of seaweed dried using hybrid solar dryer, determine the efficiency and effectivity factor of hybrid solar dryer, and to study the seaweed quality after drying.

2. Experimental method

2.1. Hybrid solar dryer design

Figure 1a. shows the schematic design of solar dryer, while figure 1b. shows the schematic design of LPG burner. Figure 2 and 3 show the LPG burner and solar dryer, respectively. The specifications of the hybrid solar dryer are shown in Table 1.

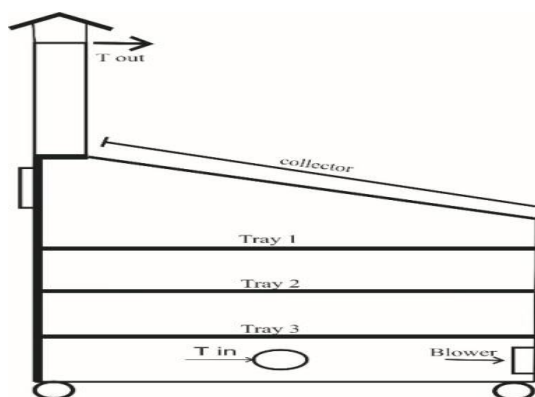


Figure 1(a). Schematic design of solar dryer

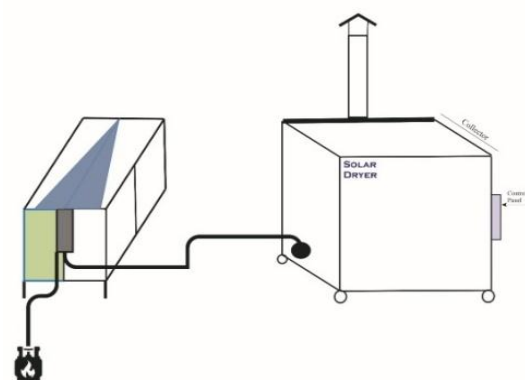


Figure 1(b). Schematic design of LPG burner



Figure 2. LPG burner



Figure 3. Solar dryer

Table 1. Specifications of hybrid solar dryer

No	Components/Specifications	Details
1	Dimension	900 x 900 x 1200 mm
2	Heat source	Solar radiation and LPG
3	Base material	Stainless steel plate 1 mm
4	Tray	Three tray, wire mesh
5	Heat collector	SUS plate 0,5 mm thick
6	Capacity	As per limit sample
7	Castor wheel	4-inch diameter
8	Frame material	Stainless steel 1,2 inch thick
9	Power consumption	300 watt / 220 vac / 1 ph
10	Accessories	Auto control panel, chimney, insulation part (made from glass wool), tray slider

The hybrid solar dryer mainly consists of solar collector, drying trays, blower, temperature controller, chimney, and a LPG burner. The solar collector is placed on the dryer's roof and was made from transparent acrylic because of its good absorbability to solar radiation, light-weighted, and cheaper compared to glass. Stainless steel was used to construct the dryer because it has good heat conductivity, strong, light-weighted, and can be easily obtained. There were three drying trays used in this experiment, with tray 1 being the closest one to the bottom and tray 3 is the closest to the dryer roof. After being heated up at the LPG burner, hot air will enter the dryer from the bottom, flows upward, then it will leave the dryer via the chimney. The heat source come from both solar radiation absorbed by the solar collector installed at the dryer's roof and the LPG burner.

2.2. Experimental procedure

All of the research activities are carried out at the Laboratory of Department of Chemical Engineering, Faculty of Engineering, Diponegoro University, Semarang, Indonesia. The materials needed in this experiment are seaweed, fresh water, and lime betel. The tools needed are digital mass balance, knife, porcelain cup, plastic sheet with the dimensions , solar radiation meter, and humidity & temperature meter (@Krisbow KW0600561). There were two drying modes performed in this experiment, which are drying using hybrid solar drying and drying with conventional (open sun drying). For hybrid solar

drying, two independent variables were used, namely tray locations and drying temperature (40, 50, and 60 °C). On the other hand, the variables that were set at constant are drying time (4 hours), weight of seaweed per tray (100 gram), and seaweed's initial moisture content, which is 94% wet basis. The initial moisture content of seaweed was determined using the oven method [10].

In this research, there are two main steps, namely the preparation step and the drying operation itself. At the preparation step, fresh seaweed is washed to remove dirt or impurities such as salt, coral, or wood. 1000 grams of fresh seaweed were soaked in fresh water with the volume equivalent to ten times the weight of seaweed. The fresh water were replaced with the new one once every day. The soaking was performed for 2-3 days until the seaweed becomes more soft, not fishy anymore, and until the seaweed color turns white. After that, the seaweed were soaked again, but this time using 1% lime betel solution. The lime betel water were replaced with the new one once per day. After three days of soaking with lime betel water, the drying process can be started.

The drying operation was done for four hours, from 09.00 AM until 01.00 PM for three days (one temperature variable each day). Firstly, prepare the solar dryer by connecting the LPG burner to the solar dryer. Next, set the dryer to the desired temperature and let the dryer operate without any load at all, this serves as a means to calibrate the hybrid solar dryer. Seaweeds that have been soaked were washed again with some water, then cut into size of 3 x 0,5 x 0,2 centimeter. After that, 100 grams of seaweed were placed inside the dryer on each tray, then the drying process can be started. Every 30 minutes, the seaweeds were weighed using digital mass balance to determine the weight reduction of seaweed. The temperature, relative humidity (RH), and solar intensity were also measured using its respective measurement tools, for once every 30 minutes. The temperature was measured at the dryer inlet, dryer outlet, and in the drying chamber. For the conventional drying, 100 grams of seaweed were cut, then placed above the plastic sheet, and dried under the sun for 4 hours, from 09.00 AM to 01.00 PM. The seaweed weight measurement was also carried out once every 30 minutes. This data will be used to determine the hybrid solar dryer's effectivity factor.

2.3. Data analysis

After the drying operation was carried out, the measured data were processed and analyzed. There are five different analysis performed in this research, namely:

2.3.1. Moisture content analysis. Using the seaweed weight data obtained from the experiment, the seaweed's moisture content at spesific time can be determined using equation (1) [11].

$$Mc = \frac{m_i - m_d}{m_i} \times 100\% \quad (1)$$

Where m_i is the seaweed mass after drying at a certain time (kg) and m_d is the weight of dry seaweed (kg), and Mc is the moisture content in wet basis (%).

2.3.2. Drying rate analysis. Aside from being used to determine the seaweed's moisture content, the seaweed weight data can also be used to determine the drying rate of seaweed, using equation (2) [12].

$$R_d = \frac{m_i - m_d}{t} \quad (2)$$

Where R_d is drying rate (kg/hour), m_i is the seaweed mass after drying at a certain time (kg) and m_d is the weight of dry seaweed (kg), and t is the drying time (hour).

2.3.3. Dryer efficiency analysis. The seaweed weight and solar radiation data measured from the experiment can be further processed to obtained the value of dryer efficiency using equation (3) [12].

$$\eta_d = \frac{m_w \cdot h_{fg}}{IAt + m_{fuel} \cdot C_v} \times 100 \quad (3)$$

Where η_d is dryer efficiency (%), m_w is the total mass of evaporated water (kg), h_{fg} is water's latent heat of vaporization, I is the solar radiation (W/m^2), A is the area of solar collector (m^2), t is the drying time (s), m_{fuel} is the mass of fuel used (kg), and c_v is the heating value of LPG (kJ/kg).

2.3.4. Effectivity factor of hybrid solar dryer. The effectivity of hybrid solar dryer compared to open sun drying can be determined by dividing the drying rate of hybrid solar dryer and drying rate obtained from conventional drying [12].

$$\text{effectivity factor} = \frac{\text{drying rate of hybrid solar dryer}}{\text{drying rate of open sun drying}} \quad (4)$$

2.3.5. Quality analysis. The quality parameter of seaweed analyzed in this experiment is the color analysis. The analysis was performed using digital colorimeter, following Hunter's method, in which three measurements value, namely L, a, and b, were used. L value represents the brightness of the sample, with the range value of 0-100 (the higher the value, the color is more bright, and vice versa). "a" value represents the chromatic color of red-green, with positive value (+) indicates high intensity of red color and negative value indicates high intensity of green color. "b" value represents the chromatic color of yellow-blue, with positive value (+) indicates high intensity of yellow color and negative value indicates high intensity of blue color [13]. The analysis was performed in the Integrated Laboratory of Diponegoro University.

3. Results and discussion

3.1. The profiles of temperature, relative humidity, and solar intensity

The measurement data of temperatures, relative humidity, and solar radiation were put into a graph to understand its relation with drying time. Figure 4 shows the profiles of temperature, relative humidity, and solar intensity at drying with the temperature of 60 °C.

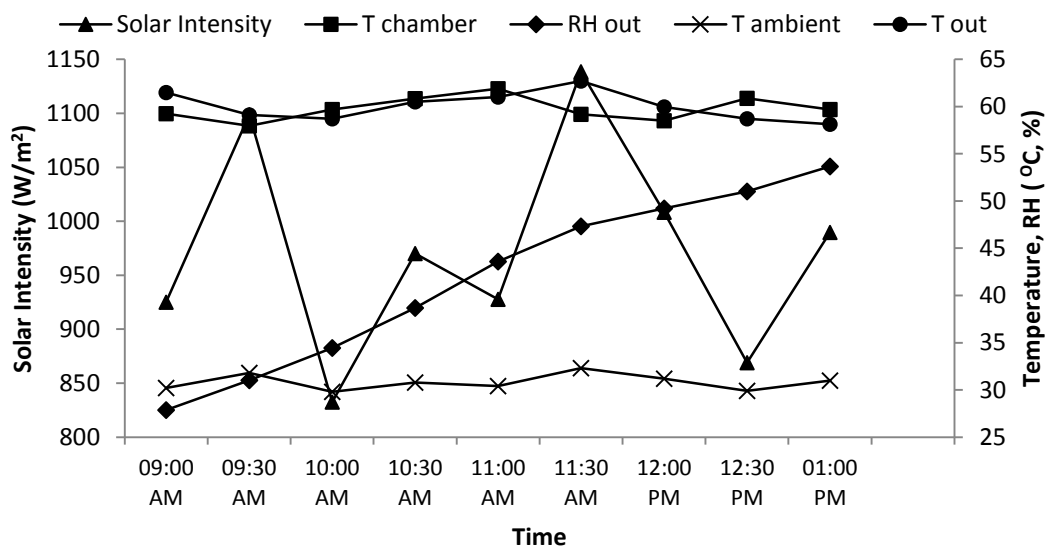


Figure 4. Temperature, RH, and solar intensity profiles at 60 °C drying

It can be seen that the temperature inside the dryer ($T_{chamber}$) is higher than outlet temperature (T_{out}). This indicates that the hot air entering the dryer will evaporate the water from the seaweed. In turn, the drying air becomes more humid because it takes water from the seaweed. This is further proved by

the increasing value of relative humidity throughout the drying process, which results in lower dryer outlet temperature [14]. The temperature inside the dryer is affected by both solar radiation and the heat provided by the LPG [15]. It can also be implied from figure 5 that the temperature is inversely proportional to relative humidity. This can be seen from the profile of T_{out} and RH_{out} , in which both show contrasting pattern (RH_{out} rises and T_{out} drops as the drying process continues). This result is similar to research performed by Suherman et al. [11].

From the figure 4, it can be seen that the maximum solar radiation recorded was at 12.00 PM, with the value of 1139 W/m^2 . This is because at 12.00 PM, the sun's position is nearly perpendicular to the earth's surface, therefore it will be more solar radiation compared to the other times. The fluctuation of the solar radiation measured in this experiment is affected by the sun's position at the time of the measurement and weather condition. The results from this experiment is different with research performed by Yuliatmaja [16], in which the recorded average solar radiation in the city of Semarang is $1536,63 \text{ W/m}^2$. This might be caused by different measurement time, geographical position, and the weather at the time of measurement.

3.2. Drying curve analysis

The measured seaweed weight data were calculated to obtain the seaweed moisture content, then plotted into a graph. Figure 5 shows the drying curve of seaweed in tray 1 (the bottom tray).

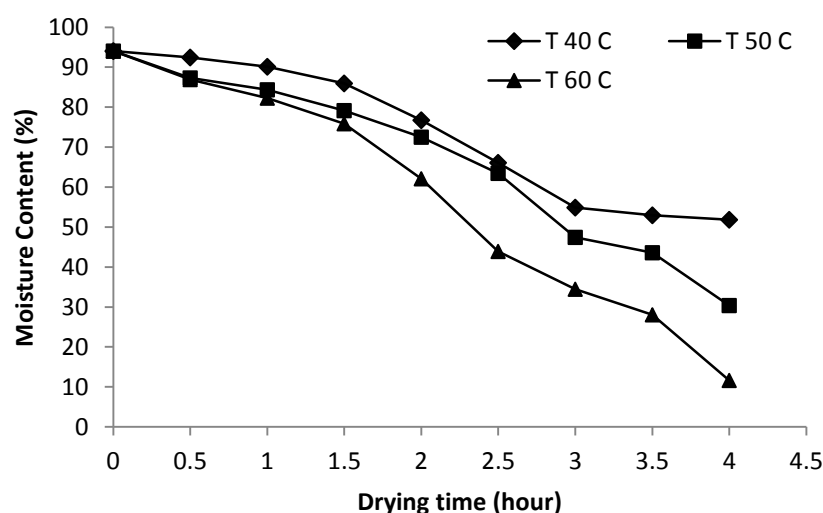


Figure 5. Drying curve of seaweed dried in hybrid solar dryer

According to the National Standard of Indonesia, the safe moisture content for seaweed products is 30% wet basis [17]. In this experiment, the safe final moisture content was reached when drying using dryer temperature of $60 \text{ }^\circ\text{C}$, with the value of 12,2 % wet basis. According to figure 5, the moisture content of seaweed will decrease as drying process continues [2]. The final moisture content of seaweed will differ depending on the dryer temperature used. Higher dryer temperature will lead to faster drying because more water will be taken from the seaweed by the drying air. This is possible because higher drying air temperature means the drying air have less amount of water. The difference of water concentration between the drying air and the seaweed will cause the water from seaweed to diffuse to drying air to achieve equilibrium, thus making the seaweed lose certain amount of water and becomes drier as the drying process continues [18,19].

3.3. The effects of drying time on drying rate

Figure 6 shows the drying rate of seaweed in tray 1. It can be seen that drying rate will gradually decrease as the drying process continues and will eventually reach a constant value. The highest drying rate value is during the early phase of the drying. This is because the moisture content of seaweed is still high, therefore it will be easier for drying air to take the water from the seaweed, thus there will be more water evaporated per unit time. The exact opposite happens during the end of the drying process. There will be much less water present on the seaweed, thus it will be harder for the drying air to take water because the water is bound inside the seaweed's inner structure. [20]. According to the figure 6, drying rate at 60 °C is higher compared to drying at 40 and 50 °C. This is because the higher the temperature, more heat will be carried by the drying air to evaporate the water from seaweed, which will speed up the drying process [12].

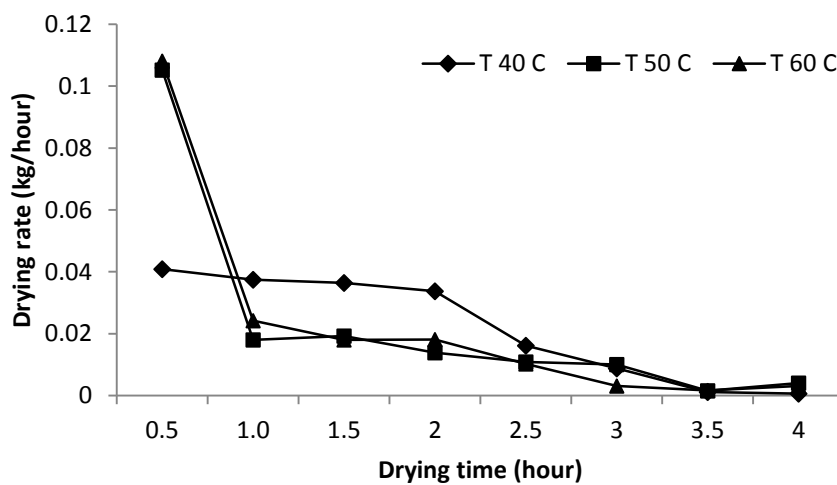


Figure 6. Drying rate of seaweed dried in hybrid solar dryer

3.4. Dryer efficiency analysis

After the dryer efficiency value were counted, Figure 7 shows the efficiency curve of hybrid solar dryer at drying temperature of 60 °C.

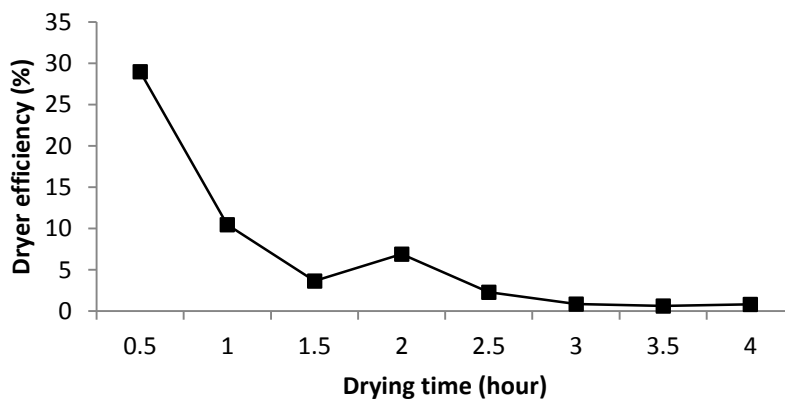


Figure 7. Hybrid solar dryer efficiency curve during drying at 60 °C

The maximum dryer efficiency was approximately 30% at 09.30 AM, which was the first 30 minutes of the drying process. The dryer efficiency decreases over time, and eventually reached constant value at 0,5% at 00.30 PM. Much like the drying rate, the dryer efficiency was high during the early phase of drying but gradually decrease as the drying process continues. According to Fudholi et al. [21], the value of dryer efficiency is proportional to the amount of heat utilized to evaporate the water from the material. At the early phase of drying there were still a lot of water from the seaweed to be evaporated, as opposed to the later phase of drying, in which there will be few water in the seaweed, making it harder for the drying air to take the water from the seaweed.

3.5. Effectivity factor of hybrid solar dryer

Effectivity factor is defined as the ratio of drying rate of seaweed drying using hybrid solar drying and drying rate of seaweed drying using conventional method. Figure 8 shows the effectivity factor of hybrid solar dryer in respect to open sun drying.

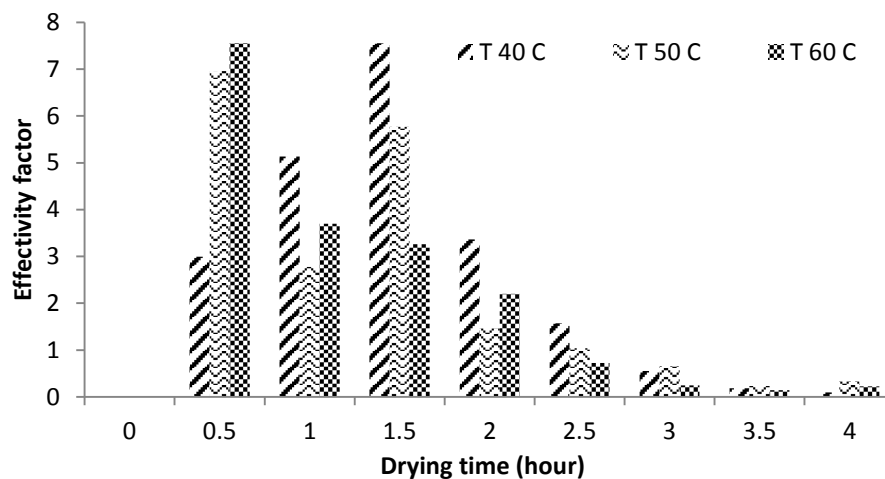


Figure 8. Effectivity factor of hybrid solar dryer

It can be seen that the highest effectivity factor value is 8, which was measured at the first 30 minutes of drying process and with the dryer temperature of 60 °C. Drying rate plays an important part on determining the value of efficiency factor. As stated in the previous section, the drying rate at the initial phase was at its maximum, therefore the effectivity value was also at its highest. Similarly, as the drying process continues, the drying rate is decreased, making the drying process less efficient, and in turn, lowering the value of efficiency factor. According to Dhanushkodi et al. [12], the value of effectivity factor is always higher than 1, except during the end of the drying process, in which the effectivity factor might be lower than 1 because the drying is less effective. It can be concluded that drying using hybrid solar dryer is more effective and efficient than conventional drying.

3.6. Quality analysis

Table 2 shows the color analysis of dried seaweed. From the table 2, it can be seen that the value of the color parameters will vary at different drying temperatures used. Based on the results, it can be concluded that drying at 50 °C gave the best color quality. It should be noted that higher L value means the sample is bright, higher value of negative “a” means the sample tend to be greenish in color, and the higher value of positive “b” means the sample tend to be yellowish in color. Therefore, the drying at 50

°C gave the best result because it indicates that there were no deterioration in sample dried at that temperature.

Table 2. Seaweed color analysis

No	Temperature (°C)	Parameter value		
		L	a	b
1	40	63	-26	30
2	50	65	-30	41
3	60	65	-23	35

4. Conclusions

A study about the performance of hybrid solar dryer with auxiliary heater for seaweed has been performed. Based on the experimental results, several conclusions can be taken. The dryer temperature, relative humidity, and solar radiation are highly dependent on the weather condition, drying time, and in the case of solar radiation, the geographical location. The safe moisture content of seaweed was reached at drying with the temperature of 60 °C. It is found that higher temperature will lead to faster drying. Also, drying process is the fastest during the initial phase of the drying, then the drying becomes slower and less effective as drying time increases, until it reaches a constant value. It is found that compared to conventional drying, drying using hybrid solar dryer is more effective, proven by the high value of efficiency factor. Quality analysis suggests that to preserve the color quality of dried seaweed, it is preferred to perform the drying with the temperature of 50 °C.

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