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Preliminary Study of Seaweed Drying under A Shade and in A Natural Draft Solar Dryer

Hooi-Kim Phang#), Chi-Ming Chu, Sivakumar Kumaresan, Md. Mizanur Rahman, Suhaimi Md. Yasir

#)Thermal and Environment Research Group,Materials and Minerals Research Unit, Faculty of Engineering, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia.

Email: phang83@gmail.com

Abstract *-A solar dryer was designed to study the seaweed drying process under natural convection and compared to a shade drying process. A dewatering pre-treatment process was initially applied to enhance drying process for both methods. The initial weight of seaweed before pre-treatment and after pre-treatment was recorded and the seaweed was then introduced into the solar drying system and shade drying system. The air temperature and relative humidityinside the solar dryer and surrounding were recorded during experiment. A representative sample on each tray was taken or final moisture content determination where the difference of seaweed weight less than 5% for subsequent measurement. The average weight loss of seaweed from pre-treatment was about 54%. The final moisutre content of seaweed for solar drying was in the range of 24-61% (db) and shade drying was in the range of 40-48% (db) with a standard deviation of final moisture content of 20.45% for solar drying and 3.78% for shade drying. The total time for solar drying inclusive of pre-treatment was 6 days and shade drying was 9 days. The drying kinetics of each method was modeled and the results of this study will be utilized to enhance the design and operations of seaweed solar dryers.*

Keywords—*Seaweed, drying, solar drying, shade drying*

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I. INTRODUCTION

Department of Fisheries (DOF) in Malaysia aims to alleviate the poverty of coastal area population by transforming the seaweed farming industry from a cottage industry to become a commercial scale industry with a high yield production. The total production of seaweed production is expected to achieve 150,000 metric tonnes which worth RM1.45 billion in 2010 (Economic Transformation Programme, 2013). In order to export the dried raw seaweed to overseas buyers, post-harvest processing to dry fresh seaweed is an essential technique for shipping.

The common post-harvest drying method that applied in Semporna is the open sun drying method. The harvested raw seaweed was spread on platform and exposed to sun or hang with rope as shown in Figure 1. The open sun drying method is favorable and performed from generations to generations where proper training in monitoring and operation on advance control panel is not required (Mercer, 2008).

The open sun drying method is discouraged for large production due to the larger area is required and it is labour intensive. Product losses or contamination is increased particularly during raining seasons due to humidity reabsorption or remoistening.

Figure 1. Seaweed Drying Method at Coastal Area

Although an electrically powered convective solar dryer has been designed and tested in Semporna for seaweed drying (Fudholi *et al.*, 2011), the farmers may not able to afford the high construction cost and electrical cost of the device. Consequently, seaweed drying is proposed to be carried out in a natural draft solar dryer and under a shade to investigate the seaweed drying behaviour.

The natural draft solar dryer consists of air opening at the bottom, drying chamber with trays and a draft enhancing chimney fitted with wire mesh at the top. The chimney with wire mesh can prevent cold inflow and has as high as 90% improvement on the efficiency of air velocity if compared to conventional chimney (Chu *et al.*, 2012).This study aims to enhance the drying rate of seaweed through the enhancement of flow with natural convection as well as without fossil fuel and electrical devices.

II. MATERIAL AND METHOD

Fresh seaweed was packed into polystyrene boxes in Semporna, Sabah and then shipped from Tawau to Kota Kinabalu. The fresh seaweed was washed and packed into polyethylene (PE) bags before being placed on the cement floor in an open area for one day for dewatering. This dewatering was named as sauna process in mini-estate seaweed farming in Semporna proposed by Universiti Malaysia Sabah. The dehydrated seaweed from PE bag was weighed and then introduced into a room under shade and in a natural draft solar dryer.The seaweed was dried under a naturally ventilated room and a natural draft solar dryer with trays. The air temperature and relative humidity inside the solar dryer and surrounding were recorded using a data logger (Testo 174H, USA) every 10 minutes.

The moisture content of seaweed was determined by a representative sample on each tray at top, middle and bottom every 3 hours from 8 am to 5 pm daily is shown in Figure 2.

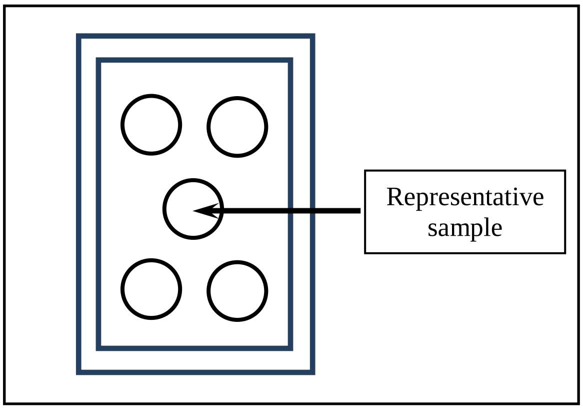

Figure 2. Representative sample from the plot of tray

The final moisture content of seaweed was determined where the difference of seaweed weight less than 5% for the subsequent measurement. The representative sample of seaweed from top, middle and bottom trays were sent to the oven for moisture content analysis using the AOAC method at 105°C for 24 hours.

The drying curves were fitted with moisture ratio models for solar drying and shade drying. The linear, Lewis, Henderson and Pabis drying models were applied to solar drying whereas the Lewis and Henderson and Pabis were used for shade drying. The drying models thatutilized for evaluation are listed in Table 1.

Table 1. Drying models tested for seaweed drying

Model	Equation
Linear	*MR = -ax + b*
Lewis	*MR = exp (-kt)*
Henderson and Pabis	*MR = a exp (-kt)*

The moisture ratio (*MR*) is difined as the following equation:

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

where *MR* is the dimensionless moisture ratio, M_i is the moisture content at time *i*, M_0 and M_e are the initial and equilibrium moisture content respectively on dry basis. In order to select a suitable drying model to describe the drying process of seaweed, the non-linear regression was implemented using the least square method for the drying models using Excel 2010. The determination coefficient (R^2) and root mean square error (*RMSE*) were used as statisticalanalysis to observe how satisfactory is the model to describe the seaweed drying in the solar drying and shade drying.

$$R^2 = \frac{SSR}{SST} = 1 - \frac{SSE}{SST} \tag{2}$$

where SSE is the sum of squared error, SSR is the sum of squared residuals and SST is the sum of squared total which explained the proportion of variance accounted for the dependent variable by the model.

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp}\right)^2\right]^{\frac{1}{2}} \tag{3}$$

where $MR_{pre,i}$ is predicted moisture ratio and MR_{exp} is the experimental moisture ratio.

III. RESULT AND DISCUSSION

The one day sauna process was taken as pretreatment process in PE bags aims to reduce the water content before being introduced into drying system. The water content was reduced by 54% in this dewatering process. The colour of raw seaweed was turned into whitish from greenish while the originally strong smell was gone. The dewatered seaweed was then introduced in solar dyer and under shade to dry the remaining moisture content of seaweed.

The air temperature and relative humidity for both surrounding and solar dryer are shown in Figure 3. The air temperature of dryer and surrounding increased from 8 am to 4.30 pm. The air temperature decreased while the relative humidity increased after 4.30 pm daily. Hence, almost no drying occurred from 5 pm until the next morning at 8 am. In the solar dryer, the air temperature was in the range of 30°C to 45°C while air relative humidity was in the range of 37% to 77%. The highest air temperature was at 45°C whereas the lowest air relative humidity was 37% in the solar dryer at 4.30 pm daily.

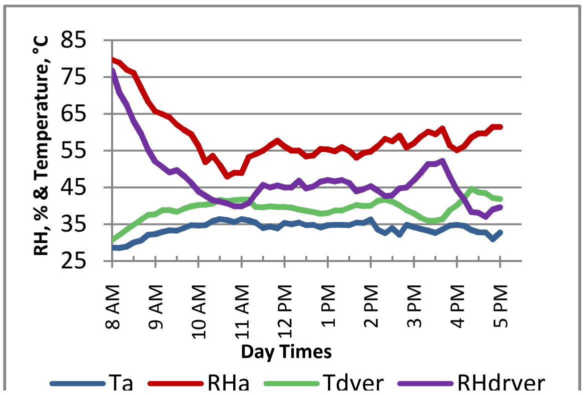

Figure 3. Air Temperature and Relative Humidity in Solar Dryer and Surrounding during Typical Day

It is observed that the drying process in solar dryer only occurs during day time due to the solar irradiation effect but not during the night time when sunlight not available. This is due to the saturated air in surrounding which flows into the solar dryer from the air opening at the bottom of the dryer when air cooled down during night time. However, the seaweed drying process in the shade drying process was continuous during the night time as well as day time. This may due to the heat storage in the cement wall as well as steady room temperature in comparison to the solar dryer. The initial moisture content and the final moisture content of seaweed that was dried in the natural draft solar dryer and under the shade are plotted into Figure 4.

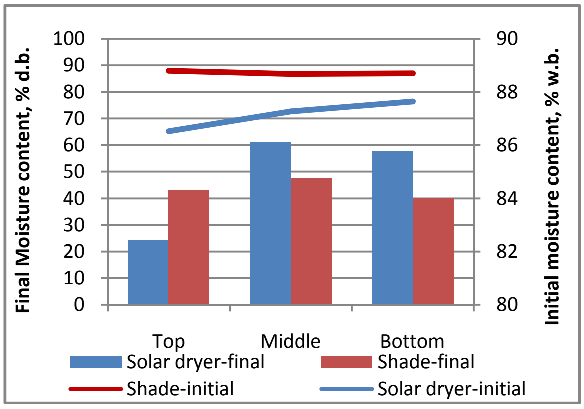

Figure 4. The Initial Moisture Content and The Final Moisture Content of Seaweed on Each Tray in Solar Dryer and under Shade

The initial moisture content of seaweed on each tray was in the range of 86% to 89% wb. The initial moisture content of seaweed in the solar dryer was slightly higher at the bottom tray if compared to the upper tray.It may due to the enhancement of draft that caused by chimney effect (Kumaresan *et al.*, 2013). The effect of solar irradiation on the top tray is vital and significant as noticed in the solar dryer. The initial moisture content under shade drying was almost the same at initial stage as the natural draft in room may be steady and the effect of solar irradiation was not obviously as compared to solar drying. The representative sample of seaweed was sent to determine the moisture content when there is only 5% difference in term of sample weight for the subsequent measurement.

The weight of the representative sample in the middle tray was the highest for both the solar dryer or under shade. The final moisture content of seaweed for solar drying was in the range of 24-61% (db) and for shade drying was in the range of 40-48% (db) with a standard deviation of final moisture content of 20.45% for solar drying and 3.78% for shade drying. This may be due to the drying characteristic of seaweed in the system. The middle tray in the solar dryer had the lowest air solar irradiation due to its position. The moisture content of seaweed sample in the middle tray under shade drying was the highest if compared to the other trays but not as high as the moisture content in the solar dryer middle tray. The air flow under shade may be steady in different directions throughout the drying process and was not significantly affected by solar irradiation. Consequently, the moisture content of middle tray can be the guideline for final moisture content measurement to ensure whether all the moisture content of seaweed attained equilibrium moisture content.

The total drying time in the solar dryer was 5 days while under shade drying was 8 days. The drying curve of seaweed drying under the shade and in the solar dryer is depicted in Figure 5 and Figure 6 respectively.

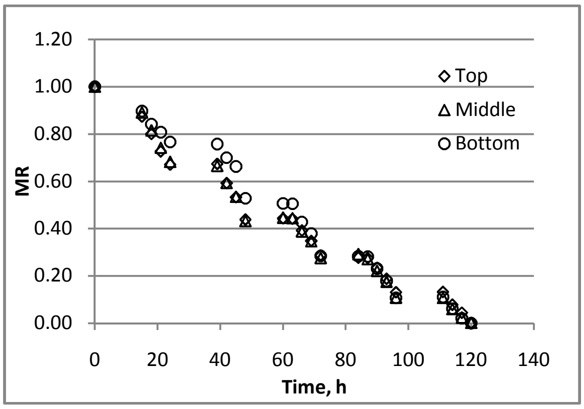

Figure 5. Moisture Ratio of Seaweed in A Solar Dryer on Each Tray

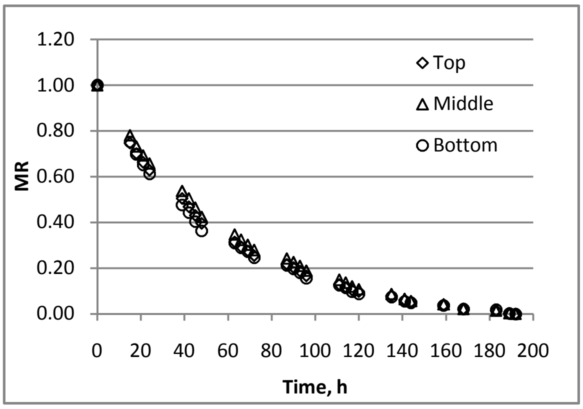

Figure 6. Moisture Ratio of Seaweed under A Shade on Each Tray

The drying curve of each method was modeled and the best modeling curve is shown in Figure 7 and Figure 8 for solar drying and shade drying respectively.

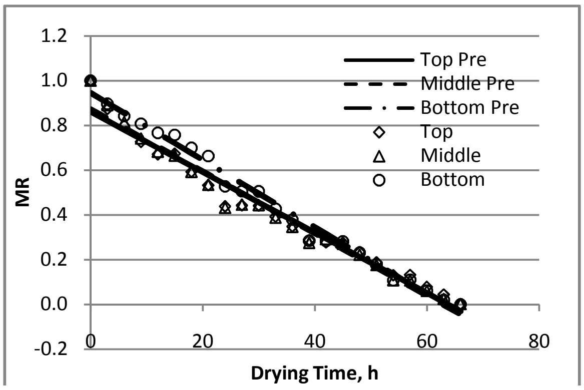

Figure 7. Measured and Predicted Moisture Ratio obtained using Linear Equation

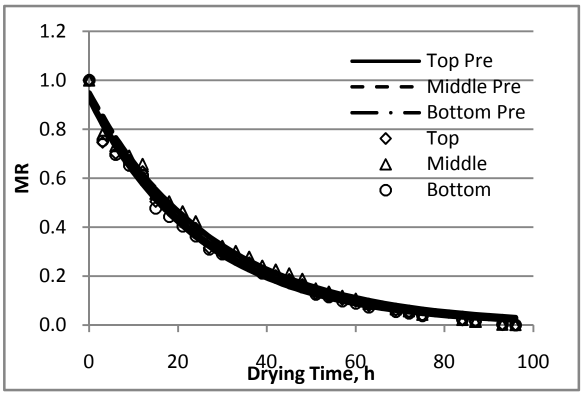

Figure 8. Measured and Predicted Moisture Ratio obtained using Henderson and Pabis Equation

The drying models for seaweed drying in the solar dryer and under the shade were fitted to the experimental data where statistical analysis through curve fitting is presented in Table 2. It was found that the best model that describes the drying kinetics for solar drying was the linear model and for shade drying was the Henderson and Pabis model.

Table 2. Regression analysis using curve fitting for solar drying and shade drying of seaweed

Tray position	**Model**	**Constant coefficients , h^{-1}**	R^2	***RMSE***
Solar Drying				
Top	Linear	a=0.0135, b=0.8613	0.9715	0.0460
	Lewis	k = 0.0321	0.9707	0.0451
	Henderson & Pabis	a = 1.0014, k = 0.0322	0.9708	0.0451
Middle	Linear	a=0.0139, b=0.8729	0.9735	0.0457
	Lewis	k = 0.0325	0.9655	0.0492
	Henderson & Pabis	a = 1.0188, k = 0.0332	0.9676	0.0487
Bottom	Linear	a=0.0150, b=0.9453	0.9889	0.0316
	Lewis	k = 0.0290	0.9173	0.0758
	Henderson & Pabis	a = 1.0706, k = 0.0313	0.9378	0.0711
Shade Drying				
Top	Lewis	k = 0.0409	0.9849	0.0340
	Henderson & Pabis	a = 0.9277, k = 0.0378	0.9895	0.0262
Middle	Lewis	k = 0.0377	0.9887	0.0294
	Henderson & Pabis	a = 0.9486, k = 0.0357	0.9910	0.0247
Bottom	Lewis	k = 0.0425	0.9854	0.0334
	Henderson & Pabis	a = 0.9242, k = 0.0391	0.9906	0.0248

IV. CONLUSIONS

The total drying time inclusive of pre-treatment that has been taken for seaweed drying in a natural solar dryer and under a shade was 6 days and 9 days respectively. All the models perform satisfactorily to describe the drying kinetics of seaweeed on top, middle and bottom tray since the values of determination of coefficient, R^2 are above 0.91. The model that selected to describe the drying kinetics for solar drying was the linear model and for shade drying was the Henderson and Pabis model. The findings of this study will be utilized to enhance the design and operation of seaweed dryers.

NOMENCLATURE

a	Drying coefficient
k, *b*	Drying constants
MR	Moisture ratio (dimensionless)
RH_a	Ambient air relative humidity (%)
RH_{dryer}	Relative humidity of solar dyer (%)
R^2	Determination of coefficient
RMSE	Root mean square error
T_a	Ambient air temperature (°C)
T_{dryer}	Air temperature of solar dyer

Subscripts

i	At time i
e	Equilibrium
0	Initial
Exp	Experimental
Pre	Predicted

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