Heat and Mass Transfer Evaluation on Sliced Red Beet (*Beta vulgaris L*) Dried by Simple Hybrid Dryer

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***Abstract*—Simple hybrid dryer is a dryer that combine greenhouse effect and other source of energy such as LPG or biomass. This dryer could increase the drying rate and the visual quality of dried product. The objectives of this research are to evaluate heat and mass transfer of sliced red beet root that dried using simple hybrid dryer by determining the drying rate constant (k) and convective heat transfer coefficient (h). There are two different capasities and three drying methods that applied in this research. The result shows that the convective heat transfer coefficient (h) for hybrid dryer ranging from 4.44 to 14.11 J s-1 m-2 ℃. The drying rate constants (k) for hybrid dryer ranging from 0.35 to 2.95 s-1, while for dryer by employing greenhouse effect ranging from 0.3 to 3.48 s-1. The k-values for both dryer are slightly higher than k-value of open direct sun dryer that ranging from 0.4 to 1.75 s-1 respectively. Employing greenhouse effect and hybrid dryer resulted in the drying rate higher than by employing direct sun drying.**

***Index Terms*—red beet root, hybrid dryer, greenhouse dryer, convective heat transfer coefficient, drying rate constat**

I. Introduction

Red beet (*Beta vulgaris L.*) is a popular vegetable in many parts of the world and primarily cultivated for its roots. It is rich with nutritional values especially fiber and sugar but have moderate caloric values. Red beet roods are consumed either fresh or after minimal processing. The main pigmen in red beet responsible for its purple color are bioactive compounds [1] and its antioxidant capacity has benefit for human health [2].

A Fresh beet root contain of high level of water content that affect its shelf life. Minimal processing such as drying aimed at extending the shelf life by reducing the water content. The most primitive drying process is Open Direct Sun Drying (ODSD), which popular in developing countries. This method is effective and economical to dry agricultural products, foods and other products. However, in ODSD, severals drying parameters such as heat input, moisture content, temperature and air drying flow could not be controled. The degradation of product quality by insect, animal and rain is the other drawback of ODSD [2].

Covering product with plastic could be used to modify ODSD to avoid product contamination. Placing a plastic also produces a greenhouse effect to trap the solar energy in the form of thermal heat radiation and prevents heat loss. The moisture is removed by natural convection or forced air flow [3], [4].

Employing greenhouse effect for drying (GHD) still have weaknesses. It still depends on the weather and climate. Improving the performance of greenhouse dryer has been carried out by several researcher. Berrauga *et al.* [5] apllied a Phase Change Material (PCM)—$CaCl_2$. $6H_2O$ in a passive greenhouse. It was reported that temperature inside the greenhouse increase 6-12 ℃ during the winter day. Rodriguez *et al.* [6] redesigned a hybrid solar dryer by distributing 70% of the energy used in pre-treatment of open solar dryers and 30% of energy in fluidized bed dryers. Combined solar and biomass cabinet dryer was designed by Okoroigwe *et al.* [7] for yam chip (*Dioscorea cayenensis*). It was reported that maximum tray temperature was 53 ℃ and the drying rate was 0.0142kg/h. Other researcher, Onipede and Agbetoye [8] dried cassava (*Manihot esculenta*) chip using a solar assisted hybrid dryer with various drying temperatures from 50 to 70 ℃ and air flow rates, and Dhanuskodi *et al.* [9] investigated a solar biomass hybrid system for cashew.

Developing model for drying product under ODSD is a complex process that involves simultaneous heat and mass transfer during the drying process. One of the most important parameter required for analysis and simulation is convective heat transfer coefficient (h). Several research developed models for moisture change during a drying process by concidering diffusion as the primary transport mechanism [10], [11].

Convective heat transfer coefficient for sun drying was evaluated by Anwar and Tiwari [12]. They used regression techniques and restricted their research on a constant drying time of 11 to 13.5h every day. Dilip and Tiwari [13] evaluated convective mass transfer and developed the empirical relation between convective mass transfer coefficient and drying time under natural and forced modes.

Thus this research was carried out to evaluate heat and mass transfer on drying of sliced red beet root with the following condition:

(a) Open Direct Sun Drying (ODSD)

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(b) Greenhouse Dryng (GHD)
(c) Hybrid Dryer with Liquid Gas (HD)

II. Theory

According to Desmorieux *et al.* [14], drying for sliced materials could be analyzed as convective drying models based on the energy and mass balance during the drying process. Heat supplied during the drying process was used to increase the temperature of the material (sensible heat) and to remove water (latent heat) from the material itself. The equation for sensible heat could be seen in (1).

$$Q_{sensible} = m_0 (Cp_p + x.Cp_w) \frac{dT_p}{dt} \quad (1)$$

while for latent heat was expressed in (2)

$$Q_{latent} = n_v.L_v a_c \quad (2)$$

Input energy was assumed only from convective heat transfer:

$$Q_{in} = hA(T_a - T_p) \quad (3)$$

The change of water in the product could be defined by (4):

$$m_0 \frac{dx}{dt} = -n_V.L_V \quad (4)$$

while

$$\frac{dx}{dt} = -k(x - x_e) \quad (5)$$

Thus, based on the energy balance, the equation to determine convective heat transfer coefficient (h) and drying rate was stated as:

$$\frac{dT_P}{dt} = \frac{k(x - x_e).L_V}{(Cp_p + x.Cp_w)} + \frac{h.A.(T_a - T_p)}{m_{0.}(Cp_p + x.Cp_w)} \quad (6)$$

III. Material and Method

A. Experimental Set up

Fig. 1 shows the part of dryer. The dryer is a cabinet type of dryer that constructed by an iron and 5mm thickness of fiber and consisted of three trays. The cross sectional area of the dryer is 3000 mm x 2000mm. The vertical distance from the ground to the top of the roof is 2000mm. This dryer is equipped with an air ventilator to allow proper air circulation.The distance between ventilator and ground is 2100mm. There is a gas burner that assembled at one side of the dryer. The burner is equipped by a chimney and a blower to flow the air drying. Air taken from the environment, flows through heat exchanger pipe and heated then blown to the drying chamber. An Isometrict picture of dryer is showed by Fig. 2.

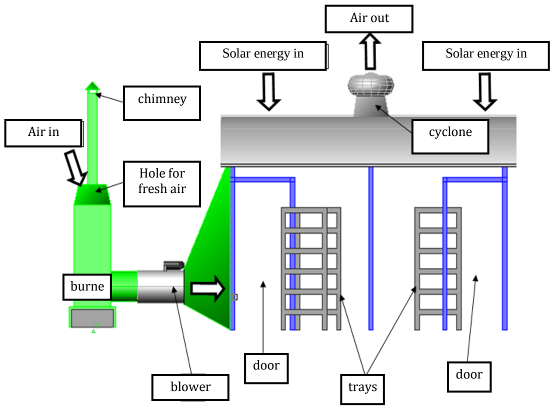


Figure 1. Part of hybrid dryer

Figure 2. An isometric picture of hybrid dryer

B. Instrumentation

A digital temperature meter was used to measure the temperature of air in the drying chamber, ambient and above the sample surface. It had a least count of 0.1 ℃ of temperature with accuracy of ±1% on the full scale range of 0–150 ℃. A loading digital balance of 0.2kg weighing capacity, having a least count of 0.01g with ± 2% on the full scale was used to weigh the sample during drying. The difference in weight showed the moisture lost during that time interval

C. Sample Preparation

Red beet root was sliced in 2mm thick and was weighed in two variations drying capacities of 3.0kg and 4.5kg, for every treatment. The samples were divided into 10 trays so that there was 0.3kg for each tray in 3kg drying capacity and 0.45kg for 4.5kg drying capacity. The same size of samples were maintained for open direct sun drying and hybrid dryer. This treatment also applied for greenhouse drying method. All of treatment was carried out in three repetitions.

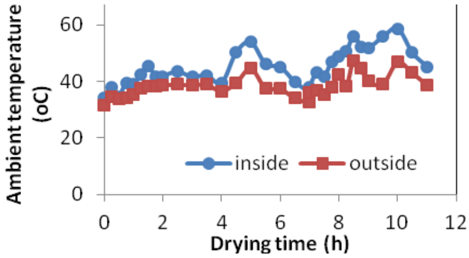
D. Experimentation

Samples were kept in the tray for the experiments. Observations for Open Direct Sun Drying (ODSD) and Hybrid Drying (HD) were taken simultaneously. The observations data were recorded from 9 AM to 2 PM at every 30 minutes interval for 11h drying. The experiment for Greenhouse Drying method (GHD) was also carried out simultaneously with ODSD for comparative study

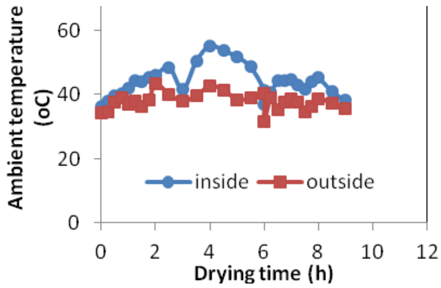
IV. Result and Discussion

A. Temperature Different

The temperature difference between outside and inside drying chamber for 3.0kg capacity was shown at Fig. 3a, while for 4.5kg capacity was shown at Fig. 3b.



(a)

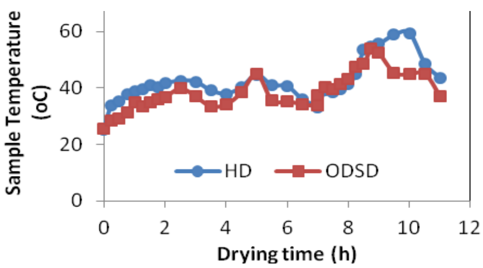


(b)

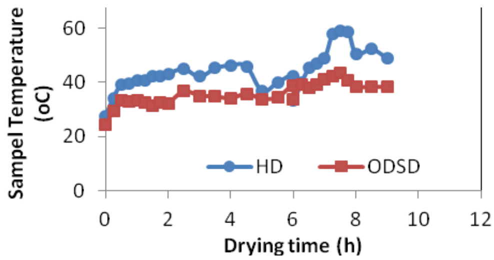
Figure 3. Ambient temperature difference inside and outside drying chamber during hybrid drying of (a) 3kg sample; (b) 4.5kg sample

Fig. 3 showed that the ambient temperature inside the drying chamber was always higher than those outside the drying chamber. The highest ambient temperature inside chamber was 54℃ while the outside chamber was 44.5℃. The average temperature inside and outside chamber were 49.2℃ and 40.6℃. Combination of greenhouse effect and heated air drying blowed to the chamber caused the increasing in the ambient temperature inside dryer. The same phenomenon occured on GHD method. Average temperature inside chamber during GHD method was 45.7℃ or about 7℃ higher than those outside the chamber. Increasing temperature caused desreasing of relative humidity that resulted in better condition for drying process.

Temperature of sample for HD and GHD also increased as result of the increasing ambient temperature of the chamber. The difference of sample temperature between ODSD and HD method could be seen in Fig. 4a for 4.5kg drying capacity and Fig. 4b for 3.0kg drying capacity.



(a)



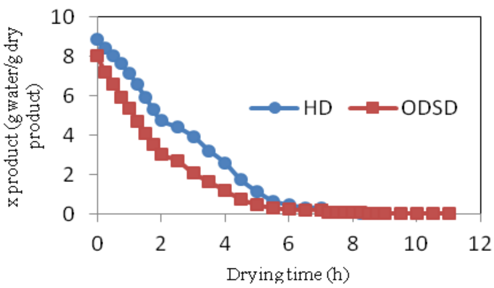
(b)

Figure 4. Sample temperature difference for HD and ODSD method during drying of (a) 3kg sample; (b) 4.5kg sample

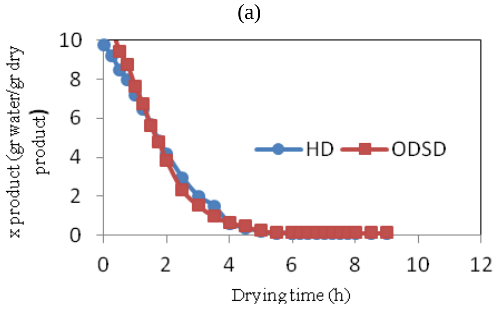
It could be seen from Fig. 4 that the sample temperatures on HD method always higher than those for ODSD. The highest sample temperature for HD was 44.1℃ while the ODSD method was 38.7℃. This condition affected the drying rate of the sample.

B. Water Content

Fig. 5 showed that there was a general decline in fraction of water (x) of the sample from 8-9 to almost zero for all of drying methods. Time requires for 4.5kg of capacity was about 11h, or 2h longger than 3.0kg. The data indicate that the water loss occured rapidly at the begining of drying process (4-5h from starting drying time) and became slower for the next drying time. Fig. 5 also showed that HD method could remove water from the sample faster than ODSD. At the beginning of the process water content of HD was higher than ODSD, but in the end of process the water content of product was similar. The drying rate by HD was higher than ODSD.



(a)



(b)

Figure 5. Water content change during HD and ODSD method of (a) 3kg sample; (b) 4.5kg sample

C. Evaluation of Convective Heat Transfer Coefficient and Drying Rate Contant

Convective heat transfer coefficient (h) was an important factor on drying analysis. In this research, the heat transfer during the drying process was assumed only occured by convection. The analysis was carried out with neglected radiation. The value of convective heat transfer coefficient was shown in Table I.

TABLE I. AVERAGE TEMPERATURE AND CONVECTIVE HEAT TRANSFER COEFFICIENT (H) VALUE

Drying capacity (kg)	Drying method	Average of Ambient Temperature			heat transfer convective coeficient (h) in W m-2 C-1		
		day 1	day 2	day 3	day 1	day 2	day 3
3	HD	41.9	49.2	-	6.25	0.69	-
	ODSD	37.0	40.6	-	4.44	1.53	-
	GHD	48.2	45.8	40.7	6.11	2.44	4.72
	ODSD	39.0	40.9	37.1	6.81	2.64	2.78
4	HD	43.7	42.2	-	9.97	7.5	-
	ODSD	37.8	36.7	-	9.72	4.44	-
	GHD	41.0	42.8	36.6	13.97	3.78	4.44
	ODSD	37.3	37.1	35.3	14.11	3.56	5.00

Table I showed that in general, the convective heat transfer coefficient (h) in HD method was higher than those on ODSD for 3.0kg and 4.5kg drying capasities while for GHD was lower than ODSD. Wind velocity affected the h-value. For HD method there was a blower that cause air movement in dryng chamber. In GHD, the movement of air was occured naturally. The h-value was also affected by the weather so that everyday had a different h-value for the same drying method. Statistical analysis was carried out to evaluate the difference between all treatment and the result showed that the h-value for all treatment was similar.

Dryng rate constant (k) was also important to evaluate the performance of dryer. The k-values for every treatment presented in Table II. For all of treatment, the k-value of day 1 was always under 1 point. Drying process for the day 1 was a lag process. On the other hand, the second day of drying process, the k-values reached the highest point. It can be seen that the k-values of HD method was always higher than those of ODSD. For GHD method, the k-value was quite similar with ODSD. It meant that the removal of water from the product occured at the same speed.

TABLE II. DRYING RATE CONSTANT VALUE (K)

Drying capacity (kg)	Drying method	drying rate constant (k) in s-1		
		day 1	day 2	day 3
3	HD	0.35	2.95	-
	ODSD	0.6	1.7	-
	GHD	0.51	3.48	0.95
	ODSD	0.55	3.3	0.15
4	HD	0.5	1.75	-
	ODSD	0.54	0.2	-
	GHD	0.3	0.87	2.8
	ODSD	0.5	0.83	5.2

D. Validation Test for H-Value and K-Value

The value of convective heat transfer coefficient (h) could be used to predict the increasing temperature of product during drying process, while the drying rate constant (k) could be used to predict the water content of the sample. The prediction of temperature and water content during HD for 3kg capacity was showed in Fig. 6a while for 4.5kg of capacity was presented in Fig. 6b.

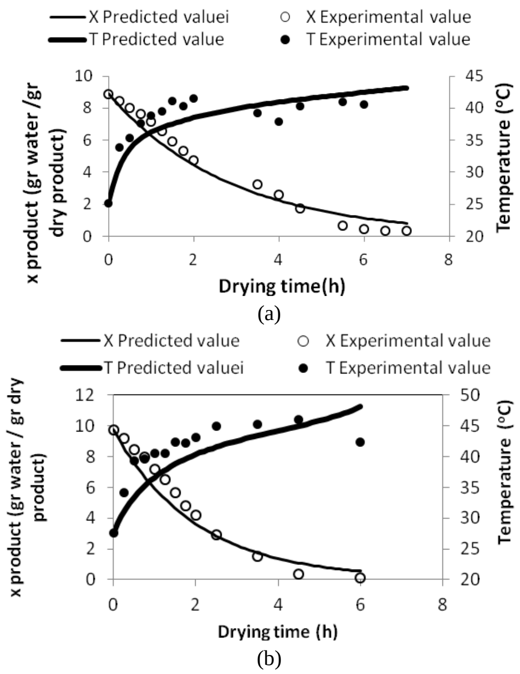


Figure 6. Temperature and water content prediction based on h-value and k-value for HD method; (a) 3kg capacity; (b) 4.5kg capacity

Fig. 6 showed that predicted values for water content (x) were in good agreement with the experimental with coefficient of determination (R^2) of 0.98 for all drying methods.

V. CONCLUSIONS

Convective heat and mass transfer for three drying method has been evaluated. The following conclussions were drawn:

1. The convective heat transfer coefficient for HD method was always higher than those of ODSD, while for GHD it was quite similar with ODSD
2. The drying rate constant for HD is much higher than those of ODSD, while for GHD was not different from ODSD

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