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Performance Evaluation of Solar and Oven Drying for Tropical Fruits

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ABSTRACT

Solar drying is the common traditional method to preserve fruits by reducing its moisture content and the microorganisms' activities, hence, slowing down the mold growth, which affect the quality of fruits. Operational cost of solar dryer can be cheaper but the drying time using solar dryer is usually longer than other drying techniques that use electricity due to the lower and inconsistent temperature within its drying chamber. In this work, bananas, papaya and pineapple were dried using an oven at temperatures of 65-85°C, and the results were compared with the outcomes of drying using a simple wood solar cabinet dryer, done in Kota Samarahan, Sarawak Malaysia. The drying profiles for the fruits dried in the oven were found to be quite similar, indicating the insignificant variation in the cell matrix structure of the fruits, and in addition, these results were supported by the small range of the estimated drying constants between 1.32 - 1.83 10^{-1} hr^{-1}. Moreover, the results showed that the increase in the temperature of drying in the oven from 65 to 75°C did not change the drying time significantly, but the drying time was reduced significantly to 70% when the temperature was increased to 85°C. The fluctuation of temperature and air flow within the solar dryer between 27-34°C and 0.12 -1.52 m/s, respectively, slowed down the drying process, resulting to prolong of drying time. The drying time to reduce the moisture content from 80-60% for the solar drying was between 31 to 74 hours while for oven drying with temperatures of 65-85°C was between 1-5 hours.

Key Words: *Fruits, Drying, Drying constant.*

1. INTRODUCTION

Solar drying has been used as a technique to preserve crop products such as fruits by reducing its moisture content to the lowest level that retards the microorganisms' activities, hence, stopping or slowing down the mold growth that affects the quality of fruits. Malaysia is a warm climate country throughout the year receiving a high amount of solar radiation that can be used for drying; the annual temperature recorded for Malaysia is between 23 to 30 °C (Hussain *et al*. [1], and Wong, *et al.* [2]) during day time making solar drying becomes one of the applicable methods for food preservation. The energy comes from the sunlight is free, and there is no emission of greenhouse gases from solar drying, reducing pollution to the environment. Therefore, solar drying not only promotes green technology but it may be also cheaper than commercialized drying techniques that use electricity.

The conventional method often referred as open sun drying is by spreading the wet material on a mat under the sun during hot days. This method is simple and cheap but it is not hygienic when it is used to dry food because contamination can occur and reduce the nutrient content of food. Many researchers have studied different designs of solar dryer, commonly consisting of an enclosed drying chamber with appropriate design of air flow to enter and exit the chamber. Different solar dryers have been discussed by Sahu, *et al.* [3], Tiwari [4], Sontakke and Salve [5], Mustayen *et al.* [6] and Patel *et al.* [7]. These dryers depend on the method of how solar energy is collected and converted to thermal energy for drying purpose. Direct solar drying has more advantages over open sun drying as it can protect fruits and vegetables from rains, dews and dusts. It is simpler and cheaper to construct than the indirect dryer but has relatively slower overall drying rates. Indirect solar dryers consist of a section that collects the hot air and transfers it to the drying chamber. A higher temperature may be obtained for an indirect solar dryer compared to a direct solar dryer but it may incur more cost for construction and maintenance. Hybrid solar dryers are the dryers that have the combination of direct and indirect solar dryers' features.

Sunlight, the source of energy, comes during the day time only, meaning drying process occurs mostly during hot days, and then it slows down or stops at night time or during raining when the temperature falls. The interruption of the drying process during the low temperature possibly causes condensation and desorption of moisture in the drying material that leads to mold growth, producing low quality dried material. The different climate at different places means different intensity of solar energy and rainfalls received at the places that cause the temperature fluctuation. Therefore, study on the temperature fluctuation and the effect of this fluctuation on drying is important, allowing further study to improve the non-continuous solar operation of solar dryer. The non-continuous drying in solar dryer may affect the quality of the dried food, and therefore the behavior of solar drying at different location must be studied. This work focused on the drying behavior of fruits dried using a solar cabinet dryer in Kota Samarahan, a small town in Sarawak, Malaysia. Results were compared with the results obtained using an oven with controlled temperature.

2. MATERIALS AND METHODS

A simple natural solar cabinet dryer following the design by Akoy *et al.* [8] was built using wood with the dimensions shown in Figure 1. The fruits were put on a mesh wire inside the cabinet. The air flow through the air vents at the bottom and at the top of the cabinet. The temperature and the air flow inside and outside the cabinet were measured. The change in the moisture content of the drying fruits was estimated based on the mass difference of the fruits.

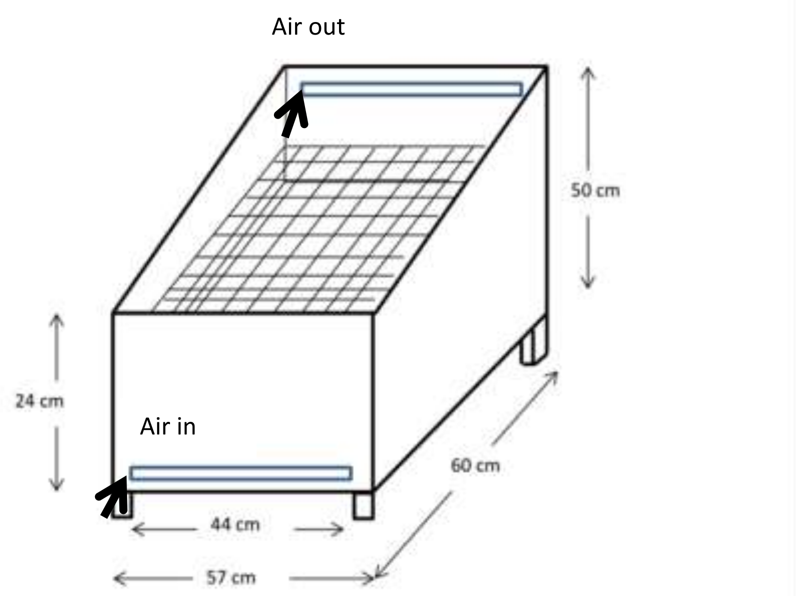

Figure 1: Isometric view of the constructed solar dryer (Akoy *et al.* [8])

Samples of 0.5 cm thickness were prepared from fresh ripe banana, papaya and pineapple bought from local market. The mass of the samples were recorded before and at different times of drying. Two batches of experiments were done in this work. In the first batch, four different temperatures, 65℃, 70℃, 75℃ and 85℃ were used for oven drying and in the second batch of drying, a solar cabinet dryer shown in Figure 1 was used.

The moisture content, X, and drying rate, R, were calculated based on Equations 1 and 2. M_o is the initial mass of the sample, while M_i and M_t refers to the masses measured at the initial and at time, t.

$$\text{Moisture content, } X = \frac{M_i - M_t}{M_o} x100 \quad (1)$$

$$\text{Drying rate , } R = \frac{X_i - X_t}{t_i - t_o} \quad (2)$$

An empirical model shown in Equation 3, which is simplified becomes Equation 4 was fitted onto the measured moisture contents for different drying time. Here, X_e refers to the equilibrium moisture content, and k_d refers to the drying constant. The fitting was

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done using the SOLVER function available in EXCEL by minimizing the standard error between the experimental and predicted values estimated using Equation 5.

$$-\frac{dX}{dt} = k_d\left(X - X_e\right) \qquad (3)$$

$$X = (X_o - X_e)\exp(-k_d t) + X_e \qquad (4)$$

$$\text{Standard error} = \sqrt{\frac{\sum\left(X_{exp} - X_{predicted}\right)^2}{n-1}} \qquad (5)$$

3. RESULTS AND DISCUSSIONS

Figure 2 shows the moisture content changes with time for different fruits dried at 85°C using an oven. The moisture content decreases and reaches equilibrium. During the early stage of drying the moisture content decreases rapidly shown by the steep curve, shown in Figure 2 and by the high drying rate shown in Figure 3. The difference in the moisture content profile for different fruits shown, in Figure 2 is insignificant indicating similarities in the behavior of mass transfer within the internal structure for these fruits.

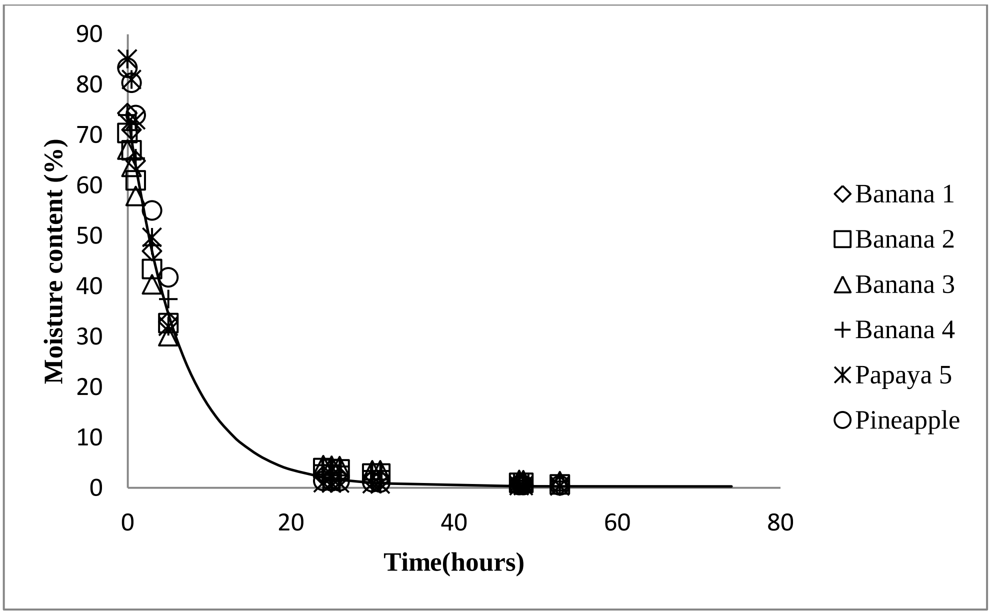

Figure 2: Moisture content versus time for bananas dried in an oven at 85°C.

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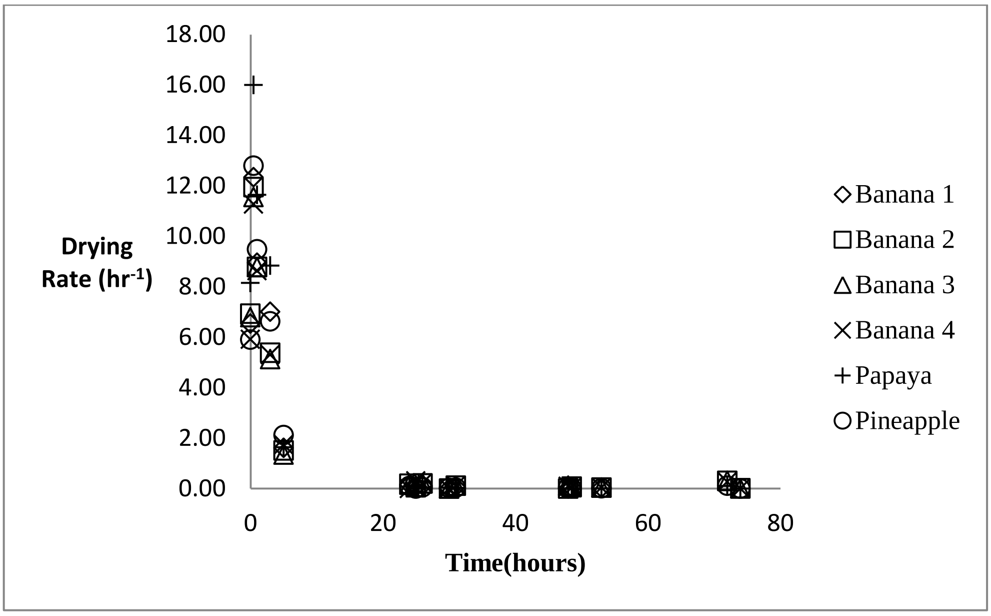

Figure 3: Drying rate time for different fruits

The plot of drying rate versus moisture content, as shown in Figure 4, indicates that there is no constant period for drying fruits. A typical drying curve usually consists of the initial rate period, constant rate period or unhindered rate period and falling rate period. During the initial rate period, the sample is warmed up to the drying temperature, and then the drying rate remains constant, indicating a constant amount of moisture is removed per unit time. The constant rate period ends when the critical moisture content is reached, and then the falling rate period begins. Theoretically, the constant rate period is governed by the external heat and mass transfer because it is assumed that, during this period, there is always a film of free moisture available at the evaporating surface. This period illustrates that the drying rate is independent of the material being dried. However, for many food and agricultural products, the constant drying period is insignificant or it does not exist because for these materials, it is the internal heat and mass transfer rates that determine the rate at which moisture can be available at the exposed evaporating surface. Similar results were obtained for the fruits dried in this work. The falling rate period is the period, which the drying rate is reduced due to internal transport limitation.

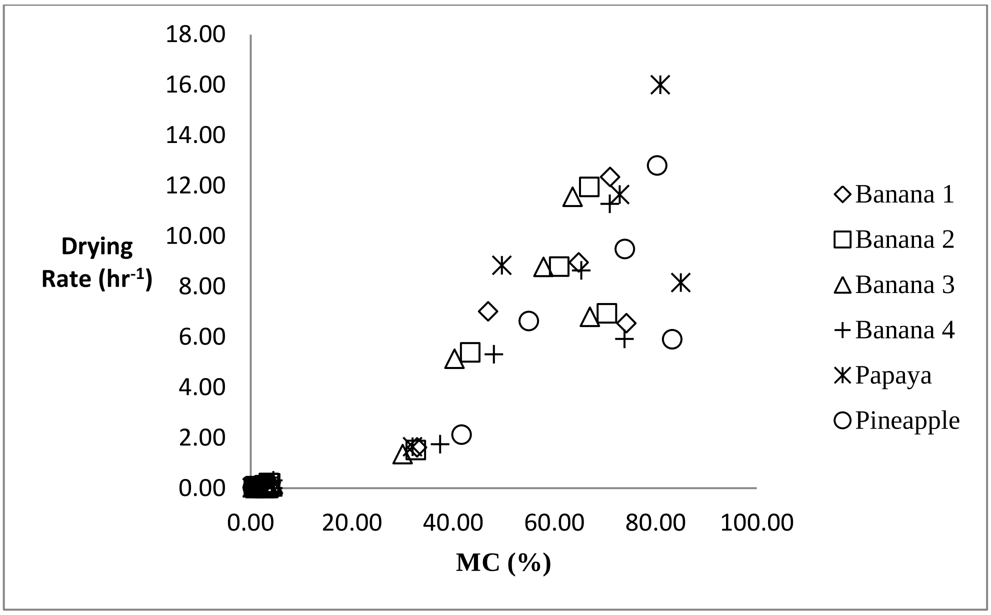

Figure 4: Drying rate versus moisture content for different fruits

Figure 5 shows the effect of temperature on the change in the moisture content for bananas during drying for different temperatures. The heat supply for drying, at high temperature, is higher, and it shortens the drying time. For example, the drying time required to reduce the moisture content from 75% to 35% was estimated to be about 5 hours for 85°C, 90 % shorter than that estimated for 65°C; it takes about 48 hours to reduce the same amount of moisture content for 65°C. However, insignificant difference moisture content observed when the temperature was changed from 65°C to 70°C. For example, the drying time required to reduce the moisture content from 75% to 38 % was estimated to be about 26.5 hours for 70°C, 1.85% shorter than that estimated for 65°C.

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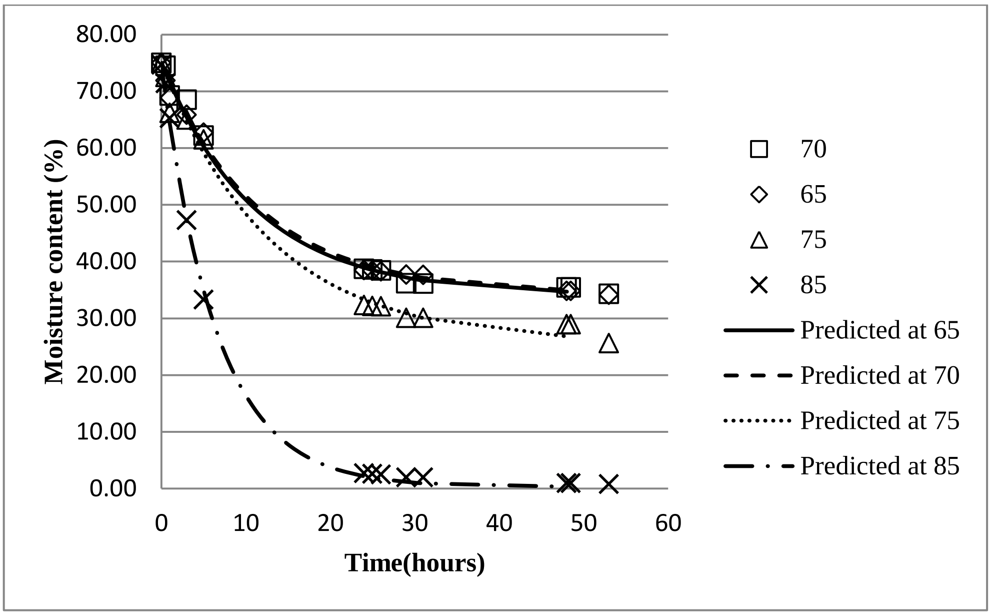

Figure 5: Moisture content versus time for different temperatures

Drying rate is affected significantly by the temperature as shown by the high drying rate for 85^{o}C compared to other temperatures for moisture content above than 40 %, illustrated in Figure 6. However, at the later stage of drying, the drying rate for all temperatures does not show much difference for moisture content below than 40%, suggesting that the internal structure of material is the controlling factor of drying. The moisture content of samples was high during the early stage of drying resulting in high drying rate; drying rate is the amount of moisture removed per unit time meaning the increase in the drying rate in the early stage of drying relates to the high amount of moisture at the surface of samples. In the early stage of drying, for the drying period less than 3 hours shown in Figure 7, the drying rate was higher than 6 hr^{-1} for all temperatures.

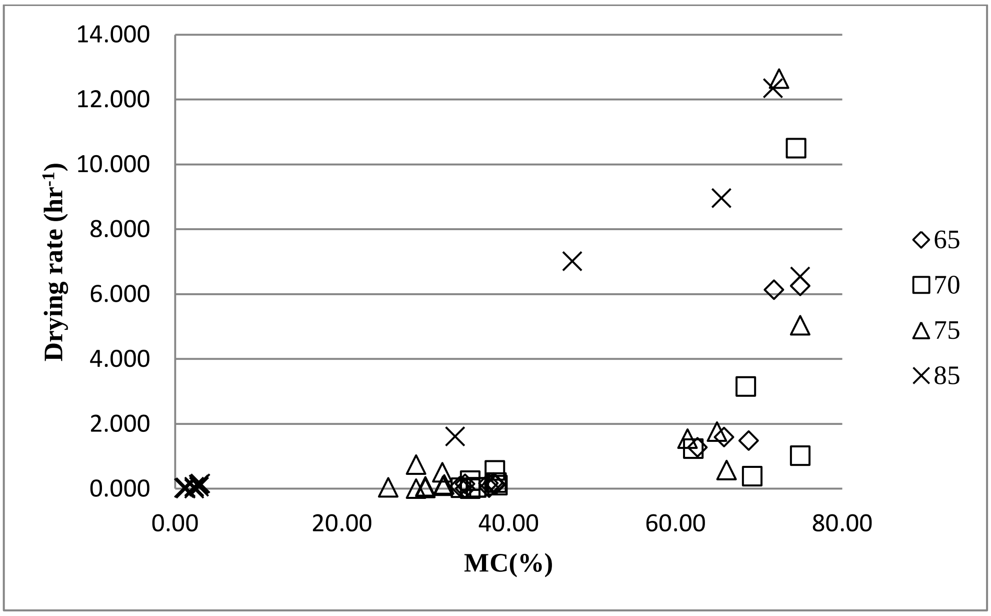

Figure 6: Drying rate versus moisture content for different temperatures

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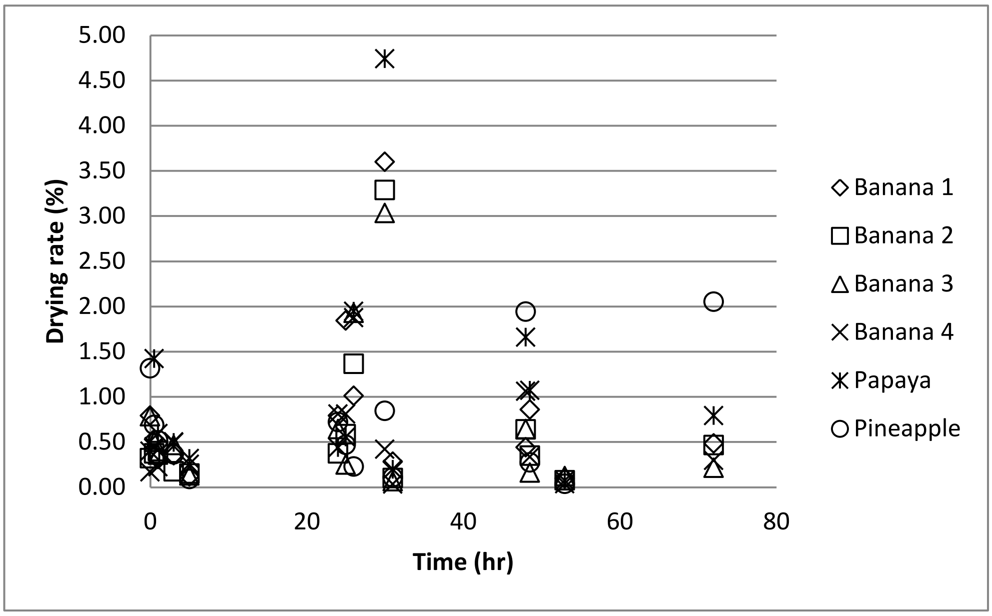

Figure 7: Drying rate of drying banana versus time for different temperatures

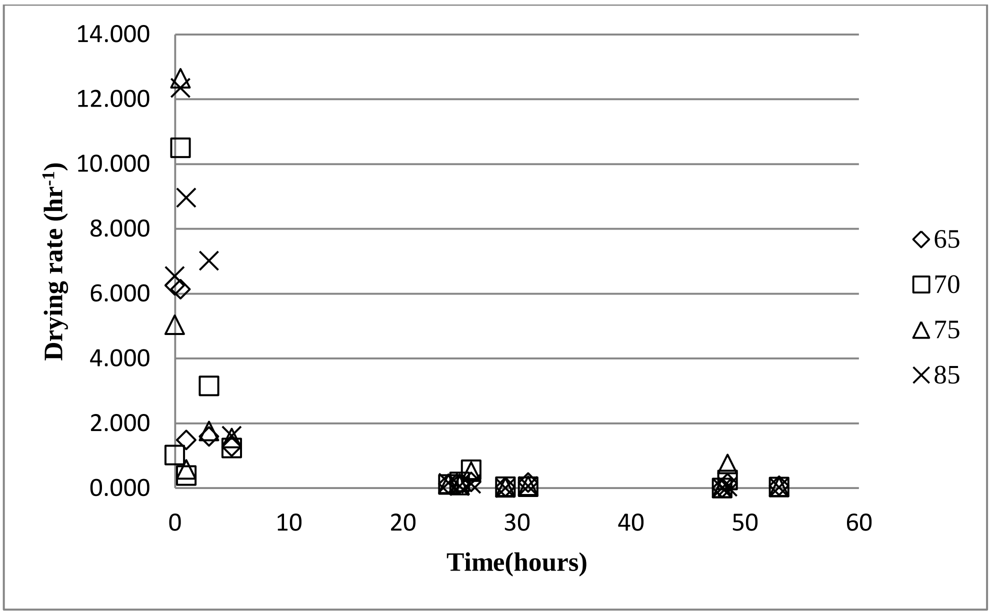

Figure 8: Drying rate versus time for solar drying

Figure 8 shows the drying rate versus time for fruits dried in the solar dryer. A different characteristic of drying curve is observed here. The drying rate increases slowly during the early stage of drying, and insignificant changes are observed during night time. The drying rate increases drastically during the early stage of second day of drying due to the high amount of moisture at the evaporative surface. At night time, the temperature and the air flow decrease, resulting in slow drying process. Although the drying process is slow during this time, it provides sufficient time for the moisture to accumulate from the internal structure to the surface of the samples. When the drying process starts again the next day of drying, the accumulated moisture on the surface of samples will be transferred easily to the surrounding air, resulting in the high drying rate. Figure 9 shows the drying rate plotted against the moisture content for the solar drying, a trend, which is different from that observed for continuous drying such as in an oven, as shown in Figure 6. The fall in the temperature during night time compared to that during the day time causes the intermittent effect for solar drying.

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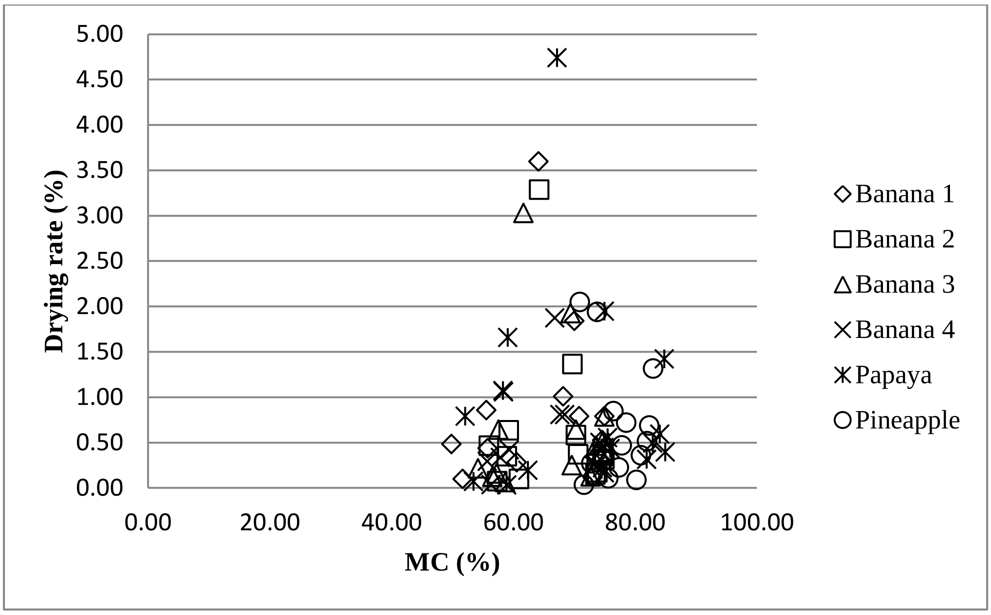

Figure 9: Drying rate versus time for solar drying

Figure 10 shows the moisture content changes for solar drying. After 74 hours of drying, the moisture content is reduced up to 50% only. The moisture content decreases significantly during the 2nd day of drying as shown by the drop of moisture content from about 80-60% in Figure 10, corresponds to the increase in the drying rate during the early stage of 2nd day of drying, shown in Figure 9. The final moisture content of fruits dried in the solar dryer, which is about 50% for all the samples except pineapple, is much higher than those samples dried in the oven. The maximum temperature, of 34°C, measured in the solar dryer was considered low that prolonged the drying time. Fans can be used to enhance the air flow inside the drying chamber, to increase the drying rate during night time. El-Shiatry *et al*. [9] observed significant decrease in the drying time for fruits and vegetables, up to 70 %, which were dried using a solar tunnel dryer with fans and heat collector; the collector was used to enhance the intensity of solar energy received for drying inside the solar dryer.

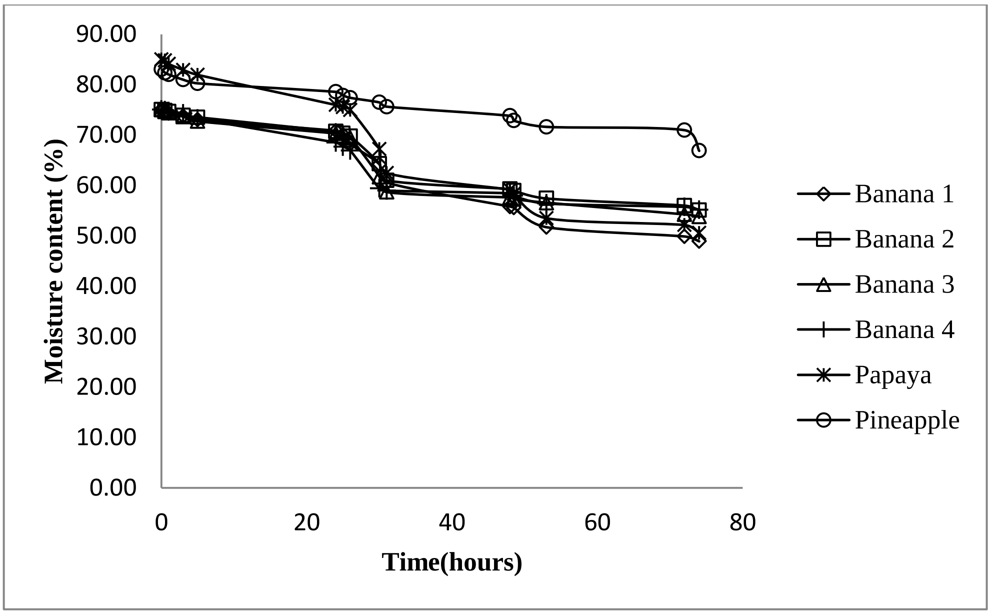

Figure 10: Moisture content versus time for solar drying

Figure 11 shows the temperature inside and outside the dryer versus time during day time. The measured temperatures inside the dryer were in the range of 27 to 34°C, while those measured outside the dryer were 28 to 31°C; the difference between the temperatures, which is up to 2°C only, indicates that the designed solar cabinet dryer is not able to retain the heat.

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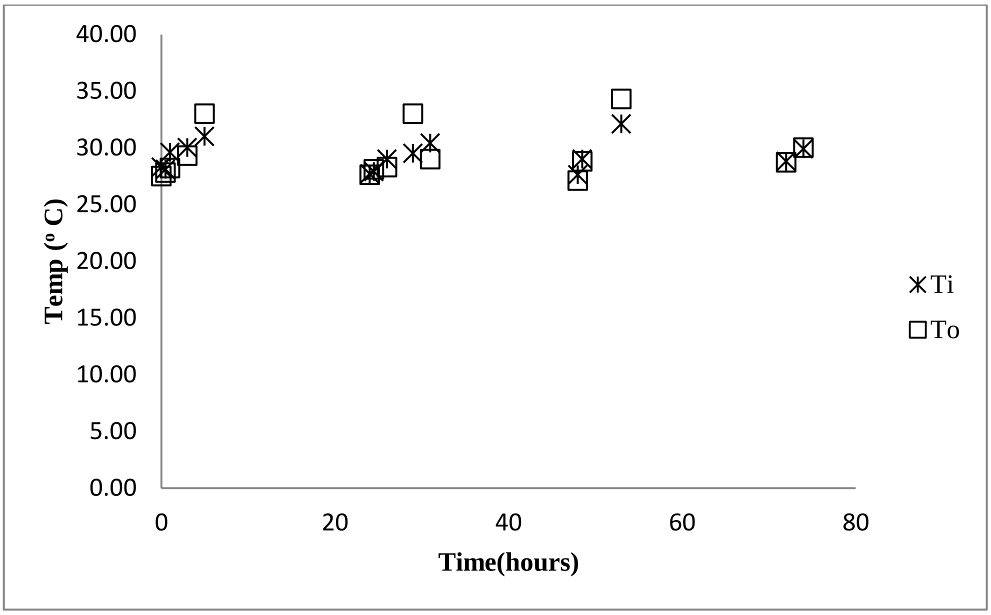

Figure 11: Drying temperature over time for solar drying

Figure 12 shows the air flow versus time. It was found that the air flow outside the dryer is much higher than the air flow inside the cabinet dryer. The air flow drops measured for the inside of the dryer is between 2-94%. Hedge *et al*. [10] found out that the effect of air flow on the drying process is lesser than the effect of temperature. They observed small difference in the drying profiles for air flow between 0.5 – 2 m/s. Although the effect of air flow on drying may not be as signifant as temperature, the additiona of fans to the solar dryer will be useful to avoid condensation when the humdity is high at night time. Condensation can happen when the temperature falls, and the humidity in the drying chamber becomes higher at night time or during raining period encouraging the readsoprtion of moisture, and it may increase the moisture content of the drying material, which may initate the mold growth.

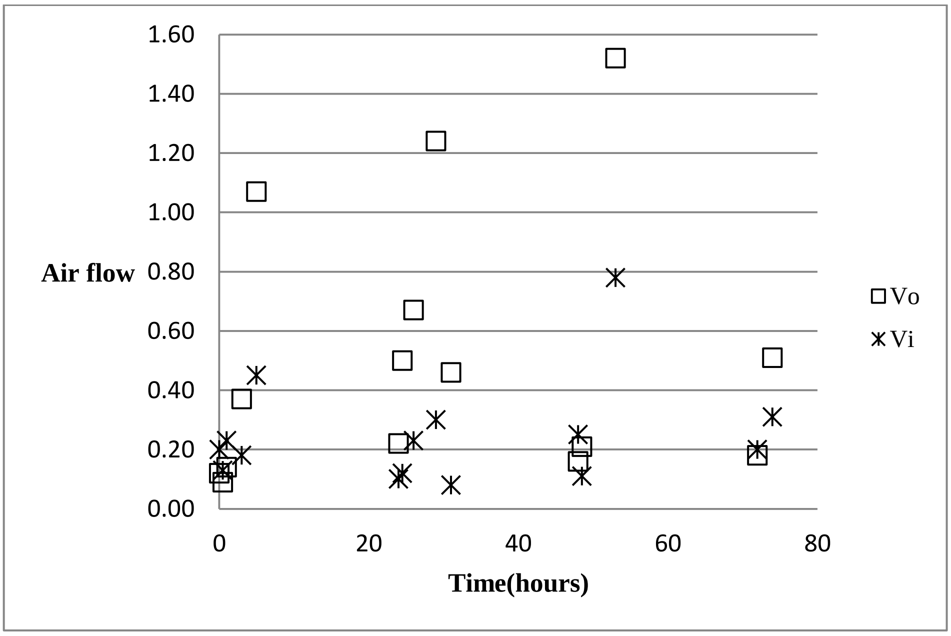

Figure 12: Air flow over time for solar drying

The moisture contents were predicted using Equations 1-5, and were fitted onto the measured data, shown in Figure 5, to give the drying constants shown in Tables 1 and 2. The effect of temperature on the drying constants was illustrated by the data shown in Table 1. The fitted drying constants for 85°C was found to be 1.53 x 10^{-1} hr^{-1} higher than that obtained for 65°C estimated to be 8.61 x 10^{-2} hr^{-1}, which relate to the high moisture diffusivity at high temperature. Insignificant variation found for the fitted drying constants for the fruits dried at 85°C, which were estimated between 1.32 - 1.83 10^{-1} hr^{-1} , as shown in Table 2. The drying time is reduced significantly by applying oven drying at 85°C, as illustrated by the data shown in Table 3. Here, 30% increase in the temperature from 65 to 85°C has reduced 70% of the drying time from 5 to 1.4 hours. Obviously, the drying time was increased when the solar drying was used, due to the lower temperature obtained with the maximum temperature achieved was 34°C only

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during the day time. The time required to reduce the moisture content of the fruits to 60% for the solar drying is much longer than that for oven drying, as shown in Table 3.

Table 1: Fitting data for Musa acuminata Diploid AA at different temperatures

Temperature (°C)	Drying constant(hr^{-1})	Standard error
65	8.61×10^{-2}	0.33
85	1.53×10^{-1}	0.96

Table 2: Fitting data for different fruits at 85°C

Fruits	Drying constant(hr^{-1})	Standard error
Banana Musa acuminata Diploid AA	1.53×10^{-1}	1.66
Banana Musa paradisiaca L	1.52×10^{-1}	1.16
Banana Musa paradisiaca Triploid AAB	1.55×10^{-1}	1.66
Banana Musa acuminate Colla	1.32×10^{-1}	1.16
Papaya	1.83×10^{-1}	1.22
Pineapple	1.40×10^{-1}	1.07

Table 3: Drying time (hour) to reduce the moisture content to 60%

Type of Fruit	Oven			Solar dryer
	65°C	75°C	85°C	(27-34°C)
Banana	5	5	1.4	31
Papaya	-	-	1.9	48
Pineapple	-	-	2.3	>74

4. CONCLUSION

In this work, bananas, papaya and pineapple were dried using an oven at temperatures of 65-85°C, and the results were compared with the outcomes of drying using a simple wood solar cabinet dryer. The drying profiles for the fruits were found to be quite similar, indicating the insignificant variation in the cell matrix structure of the fruits, and these results were supported by the small range of the estimated drying constants between 1.32 - 1.83 10^{-1} hr^{-1}. In addition, the results showed that the increase in the temperature of drying in the oven from 65 to 75°C did not change the drying time significantly, but the drying time was reduced significantly to 70% when the temperature was increased to 85°C. The drying time for solar drying was found to be significantly longer, which can be more than 74 hours for reducing the moisture content to 60%, due to the uncontrollable lower temperature inside the drying cabinet. However, oven drying is more costly due to the higher energy usage. The drying time for solar drying can be reduced by adding fans to enhance the air flow and by adding the solar collector to increase the temperature within the solar dryer.

5. ACKOWLEDGMENT

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5. REFERENCES

[1] Hussain, M., Yusof, K.W., Mustafa, M.R., Mahmood, R. and Shaofeng, J., "Projected changes in temperature and precipitation in Sarawak of Malaysia for Selected CMIP5 Climate Scenarios", *International Journal of Sustainable Development Planning*, 2017, Vol. 12, No 8, pp. 1299-1311.

[2] Wong, C-L., Yusop, Z. and Ismail, T., "Trend of Daily Rainfall and Temperature in Peninsular Malaysia Based on Gridded Data Set, *International Journal of GEOMATE"*, 2018, Vol 14, No. 44, pp. 65-72.

[3] Sahu, T.K., Gupta, V. and Singh, A.K., "A Review on Solar Drying Technique and Solar Greenhouse", *Journal of Mechanical and Civil Engineering*, 2016, Vol. 13, No. 3, pp. 31-37.

[4] Tiwari, A., "A Review on Solar Drying of Agricultural Produce", *Journal of Food Process Technology*, 2016, pp. 7-9.

DOI: 10.31695/IJASRE.2018.33025

[5] Sontakke, M. and Salve, S.P., "Solar Drying Technologies: A Review" *International Refereed Journal of Engineering and Science*, 2015, Vol 4, No. 4, pp. 29-35.

[6] Mustayen, A.G.M.B., Mekhilef, S and Saidur, R.. "Performance Study of Different Solar Dryers", *Renewable and Sustainable Energy Reviews,* 2014, Vol. 34, pp. 463–470.

[7] Patel, A.H., Shah, S.A. and Bhargav, H., "Review on Solar Dryer for Grains, Vegetables and Fruits", *International Journal of Engineering Research & Technology*, 2013, Vol. 2, No. 1, pp. 1-7.

[8] Mohamed Akoy EL-A. O., Ismail, M. A., Ahmed, El-F. A.and Luecke, W. " Design of solar dryer for dates". AMA, 1998, Vol 29, No. 3, 59-62.

[9] El-Shiatry, M.A., Muller, J. and Muhlbauer, W., "Drying Fruits and Vegetables with Solar Energy in Egypt", *Agricultural Mechanization in Asia, Africa and Latin America*, 2014, Vol. 22, No. 4, pp. 61-64.

[10] Hedge, V. N., Hosur, V. S., Rathod, S. K., Harsoor, P. A. and Narayana, K.B., "Design, Fabrication and performance Evaluation of Solar Dryer for Banana", *Energy, Sustainability and Society*, 2015, pp. 5-23.

DOI: 10.31695/IJASRE.2018.33025