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An Investigation of Solar Dryers with Different Covers for Solar-Dried Cultivated Bananas

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Abstract

This research made comparison studied of the efficiency of a solar dryer covered with polycarbonate sheet and glass sheet under the same ambient environment. The experiment was carried out during the period of February-March, 2022 in Thailand. Cultivated bananas were dried from 8:00 a.m. to 4:00 p.m. for four consecutive days and the experiments were repeated twice. Data collected from the experiment were irradiance, temperature, and banana mass from both solar dryers and the controlled sample under natural sunlight exposure. The results from the repeated experiments showed that the maximum global solar radiation was 928.96 W/m^2, with mean value of solar radiation of 549.05 and 543.39 W/m^2 for round 1 and 2; respectively. The temperature inside the solar dryer covered with glass sheet was found higher than the one covered with polycarbonate sheet by 3-5°C, and higher than the ambient air temperature by 25-28°C. As a result, the bananas in the solar dryer covered with glass sheet was dried quicker than the one covered with the polycarbonate sheet. The final moisture contents for dried bananas from round 1 and 2 were 4.34, 5.22% (wet basis, wb); 5.07, 6.21% (wb); and 12.01, 14.37% (wb) for the solar dryer covered with glass sheet, dryer covered with polycarbonate sheet, and the sample directedly exposed to sunlight; respectively. According to the same drying time comparison, the solar dryer covered with glass sheet was 3% faster than the dryer covered with the polycarbonate sheet and was also around 45% faster than the sample under natural sun drying.

Keywords: Polycarbonate, Glass, Solar Dryer, Cultivated Banana

1. Introduction

Solar energy is a type of very useful energy without impacts on climate. Solar energy is used either directly and indirectly, e.g., solar power or solar drying, which is an old method (1-3) and has been used widely for dried vegetables and fruits preservation over a period of time. However, natural sun drying are exposed to contamination from dirt, dust, and insects; and causes decomposition as well as get wet on rainy days (4-6). Thus, researchers in many countries have developed solar dryers for drying products to substitute for natural sun drying. Most models of developed dryers have cover roofs to prevent contaminations, with space for solar radiation (solar collector) to convey heat through products for drying, called indirect-mode natural convection solar dryers. As for solar drying with direct solar radiation on products, this type of dryers is called direct-mode natural convection solar dryers (7-8). Product drying is based on natural convection (9-10) and forced convection, depending on design by researchers for certain areas. In order to respond to user needs, national and international researchers have developed household dryers and commercial dryers.

S. Janjai et al. (11) developed a greenhouse-like solar dryer or “parabola dome.” The dryer contains a curved parabola roof as the component, and is installed on concrete floor and covered with polycarbonate sheet. A solar ventilator is on the back to blow the air out of the dryer. An air vent is on the front to let the air flow into the dryer for replacing the blown out one. The parabola shape helps receiving sunlight efficiently all day long, reducing wind resistance, and creating beautiful look.

The cover of most solar dryers are polycarbonate sheets, of which key property is to filtrate UV, as a result retains the color of the products similar to the its original colors. Because the polycarbonate sheets are expensive and rarely found in local areas, we were interested to study other types of materials with the similar property to polycarbonate sheets. The alternative solar dryer studied in this experiment was covered with a glass sheet for the price of glass being about 50% cheaper than polycarbonate. The glass covered dryer was compared with the popular polycarbonate sheet based on direct mode of natural convection. The efficiency of solar dryers covered with different materials for drying cultivated bananas were studied under temperature variation and moisture change.

2. Materials and Experiment

2.1 Equipment preparation and installation

The cover material was installed as the roof-deck and was oriented in the north-south direction at Pathum Thani, Thailand (14.02 °N, 100.52 °E) in an outdoor space and was not disturbed by shadows of trees or the building. As a result, it was fully exposed to sunlight. Two solar dryers were used. The first dryer was covered with a glass sheet, and the another one was covered with the conventional polycarbonate sheet. To receive full sunlight, the cover plates were tilted at an angle of 14.02 °equal to the latitude of experimental station. Both dryers were designed as in Figure 1.

The solar dryers in this research were based on direct mode natural convection. Products inside these solar dryers would receive thermal energy directly from sunlight. The internal temperature of dryer increases the cover prevent products inside from contamination by dust, insects, rotten if soaked by rain. Moreover, the product's color would remain as close to the original condition as it is not directly exposed to ultraviolet light.

The construction of the solar dryer was shown in Figure 1 with the trays inside for placing products. There was the air vent on the lower part in front. The air will flow pass the products up high and flow out at air vent at the upper part of the back panel of the dryer.

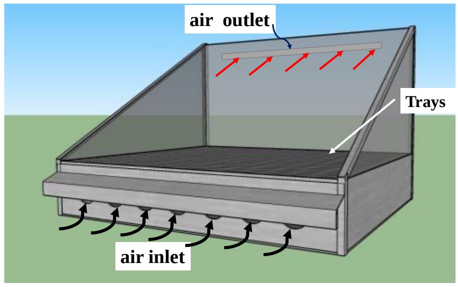

Figure 1 Description of the solar dryers studied.

Thermocouples (type K, accuracy ±2%) were used to measure temperatures under natural sun drying and inside the dryers. Global solar radiation was measured by a pyranometer (model cmp11, accuracy ±0.5%). Temperatures and global solar radiation would be recorded by a multi-channel datalogger (Yokogawa, Model DC100) every 10 minutes. A digital scale was used to weigh banana mass hourly.

The thermocouples were installed inside of both dryers at the middle position of the trays. The another one was installed outside dryers to measure the ambient temperature. The position of the thermocouple is shown in Figure 2.

2.2 Experimental procedures

Solar dried bananas experiments were carried out for two round repetitions. The initial mass of the sample cultivated bananas in each round was between 42-45 g. The mass of the samples dried inside two dryers and the sample that was dried directly under natural sunlight were weighed hourly until their masses in all three cases were stable.

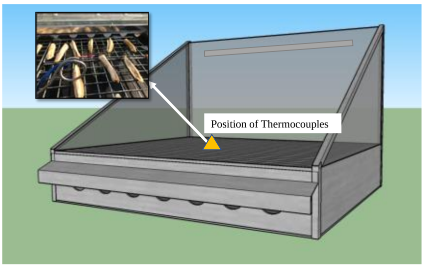

Figure 2 Thermocouples installation positions for temperature measurements.

Temperatures and irradiance were recorded from 8:00-16:00 hrs for 8 consecutive days. Then, the data obtained from both rounds of the experiment was analyzed to find effects of temperature, moisture contents variations on the efficiency of the dryers.

2.3 Data analysis

The dry solid mass of the banana after drying was determined by the oven method (103°C for 24 hrs, accuracy ±0.5%) (2). Finally, the moisture content (M; (%, wb)) during drying was estimated from the weight of the banana and the dried solid mass of the banana by Equation (2.1.) (12)

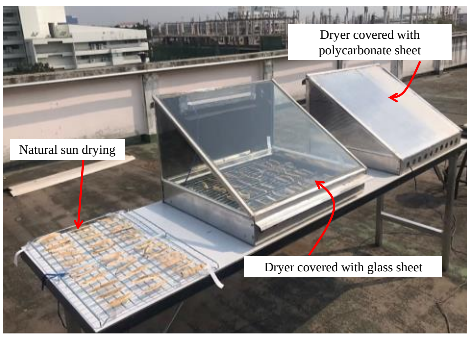

Figure 3 Shows the two solar dryers with different covered materials and another one dried under natural sunlight.

$$M = \frac{m - m_{solid}}{m} \times 100 \tag{2.1}$$

Where M is moisture contents, m is banana mass at time (t) and m_{solid} is mass of solid product both in gram unit.

Data from the pyranometer were calculated for irradiance by Equation (2.2)

$$V = \frac{I}{R} \tag{2.2}$$

Where I is global solar radiation (W/m2), V is Electric potential (V), and R is Response of the pyranometer (sensitivity); is 5.49 (mV/W.m2).

Then, data from Equation (2.2); collected every 10 minutes were averaged into hourly irradiance. Then, it was displayed in graphs to study the variation of irradiance, temperatures, and moisture contents of bananas during the experiment.

2.4 The efficiency of the solar dryers

The data from the experiment were used to calculate the efficiency of the dryers by the ratio of energy required to evaporate moisture through the heat supplied to the dryer. The energy for drying was solar energy. Thus, the efficiency of the dryers are calculated by Equation (2.3) (13).

$$\eta\ (\%) = \frac{mh_{fg}}{IA} \times 100 \tag{2.3}$$

Where η is the efficiency of drying , m is mass of water evaporated from the product (kg/s), calculated from (m_i-m_f/t), m_i is initial mass of product, m_f is final mass of product, t is time used in drying process until 12% moisture (%,wb) (h), h_{fg} is latent heat of vaporization (kJ/kg), A is global solar radiation space in the dryers (m^2) and I is global solar radiation incident on the dryer (kW/m^2).

3. Results and Discussion

3.1 Experimental results

The temperatures and global solar radiation from the multi-channel datalogger from the studied of drying bananas with 2 different types of dryer cover were averaged to hourly and then were displayed in graphs to show the variation over the time of the days.

According to the result in Table 1, the maximum temperature in round 1 for the dryer covered with glass sheet was 65.67°C. In the meantime, the maximum temperature in the dryer covered with the polycarbonate sheet was 62.00°C while it was 40.48°C for the ambient.

Table 1 The maximum, minimum, and means of the temperatures during the experiment.

	Glass (˚C)	Polycarbonate (˚C)	Ambient air (˚C)
Round 1			
Maximum	65.67	62.00	40.48
Minimum	34.13	32.65	28.17
Mean	53.19	50.04	35.75
Round 2			
	Glass (˚C)	**Polycarbonate (˚C)**	**Ambient air (˚C)**
Maximum	68.53	64.17	40.78
Minimum	34.40	32.70	30.30
Mean	54.78	51.29	36.90

As a result, the temperature inside the dryer covered with glass sheet was higher than the temperature inside the dryer covered with the polycarbonate sheet. In round 2, the maximum temperature in the dryer covered with glass sheet was 68.53°C. At the same time, the temperature in the dryer covered with the polycarbonate sheet was 64.17°C and the ambient air temperature was 40.78°C. The data from both rounds of the experiment were displayed in Figures 4 and 5; respectively.

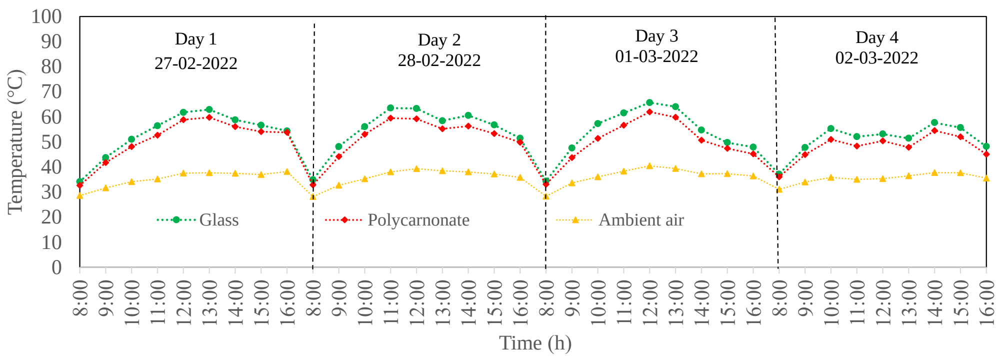

Figure 4 Variation of air temperature inside and outside the dryers with time between February 27-March 2, 2022.

Figures 4 and 5 shows the comparison of air temperatures at the different cover and ambient air temperature for the two rounds of the solar drying banana experiments. The temperature in the solar dryers with different covered materials were varied within a narrow band (3-5°C). Furthermore, the temperature inside the dryer covered with a glass sheet was higher than the temperature inside the dryer covered with polycarbonate, this was because glass has higher transmittance (0.8-0.9) than the polycarbonate (0.7-0.8) for short wave solar radiation range (0.3-3.0 μm) (14-15). In addition, temperatures for dryers with covers were significantly higher than the ambient air temperature; nearly the same with the previous work in which the temperature were different in the range of 20-30°C (11). However, the temperature was sometimes fluctuated for days the poor weather and cloudy skies. The fluctuations in temperature during the day will affect the drying time. However, the air temperature was found to have a stronger effect especially on the first day of drying. This is because the banana needs to be heated to keep the surface of the banana tight and not rotten

The two rounds of banana drying experiments were conducted during February-March in 2022. During the experiment days, solar radiation increased obviously from 8 a.m. to noon but it considerably decreased in the afternoon with fluctuations due to cloudy sky. There were also significant fluctuations in solar radiation during the second experiment. The variation of the solar radiation of the two rounds is shown in Figures 6 and 7.

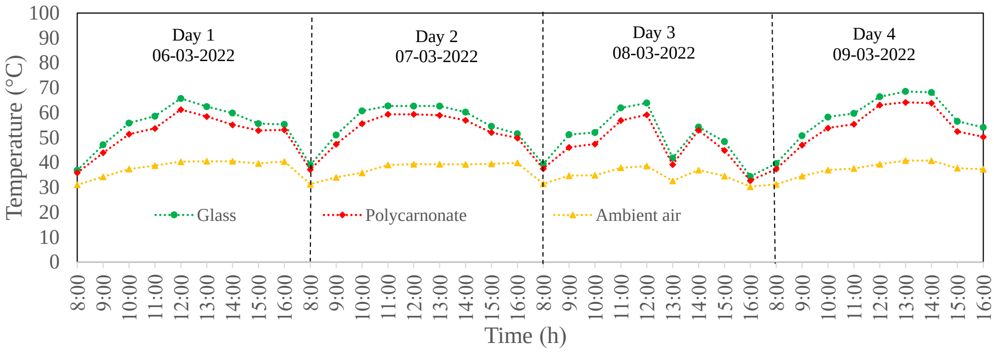

Figure 5 Variation of temperature inside the dryers and ambient during time of the days between March 6-9, 2022.

Also, irradiance would be congruent with the temperatures inside and outside of the dryers. That is, if the solar radiation intensity was high, the temperatures would also increase. This occurs when the sun's rays pass through the cover, it falls on the tray of the dryer. The tray's surface absorbs shortwave solar radiation and emits solar radiation in the infrared range. This causes the temperature of air inside the dryer to heat up, thus creating a good greenhouse effect in the dryer.

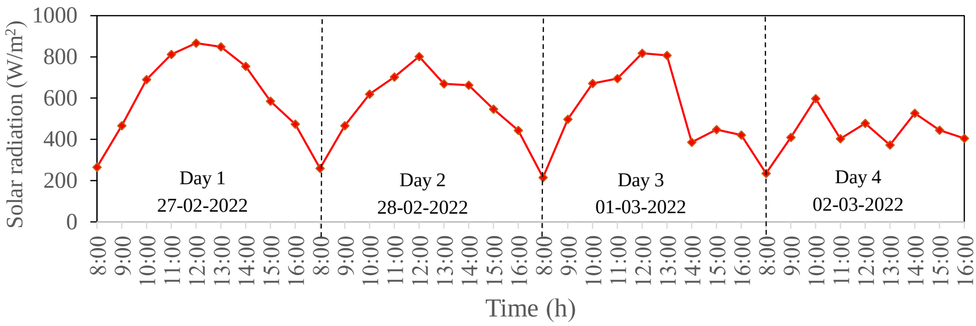

Figure 6 Variations of solar radiation with time of the day between February 27-March 2, 2022.

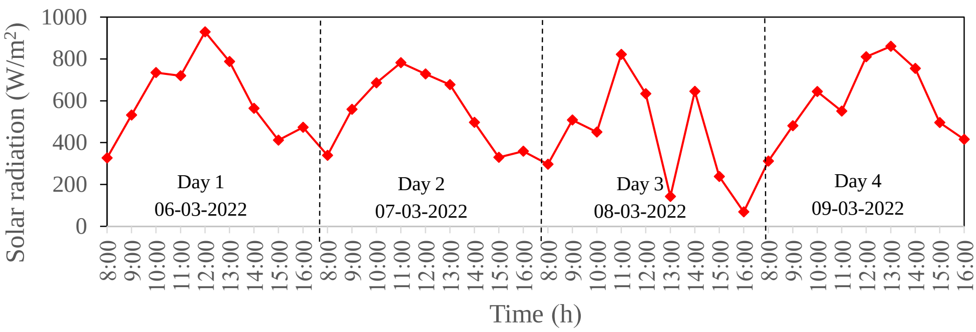

Figure 7 Variations of solar radiation during time of the day between March 6-9, 2022.

For moisture content of the products (Figure 8) in the round 1, it was found that in round 1 the banana in dryer with glass sheet cover contained initial moisture content of 65.44% (wb) and was reduced to a final moisture content of 4.34% (wb). While for the dryer covered with the polycarbonate sheet, the moisture content was decreased from 64.90% (wb) to 5.07% (wb). The one for natural sun drying was placed on grate lost the least moisture content from its initial of 65.04% (wb) to only 12.01% (wb) after four days drying. The result for round 2 was shown in Figure 9, on day 1, the moisture content of the dryer with polycarbonate cover is lower than that from the glass due to its initial moisture contents. The sample bananas in the dryer covered with glass sheet contained lost its moisture content from 70.40% (wb) down to 5.22% (wb). While the dryer covered with polycarbonate sheet had an initial moisture content of 68.04% (wb) and it was reduced the final moisture content of 6.21% (wb). And lastly for the ones placed on the grate for direct sun drying, the moisture content was reduced from 69.28% (wb) down to 14.37% (wb). In comparison of all the three cases, it was found that banana dried in the dryer covered with glass sheet contained the lowest moisture content among the three cases. Also, the moisture content was found to reduced very quickly in the initial phase of the experiment. This was in agreement with previous studies, where the moisture content decreased by more than 20% during the first day of the experiment (11, 16-17).

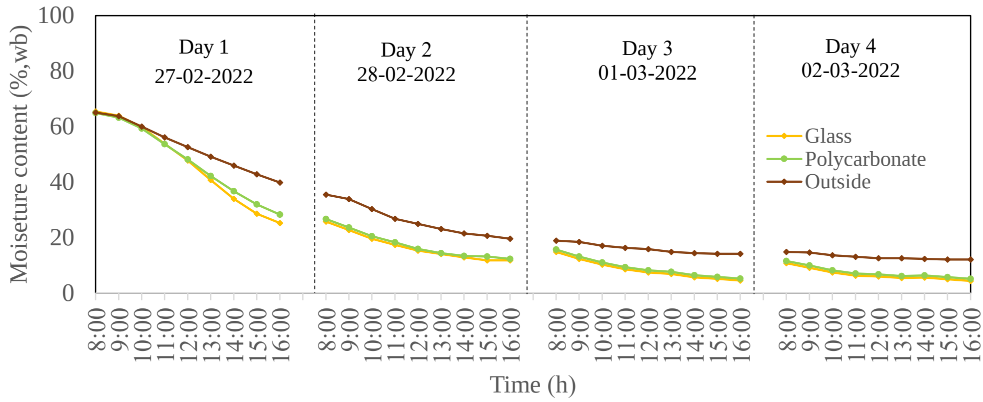

Figure 8 Comparison of moisture content from bananas inside the two dryers and under the natural sun drying between February 27-March 2, 2022.

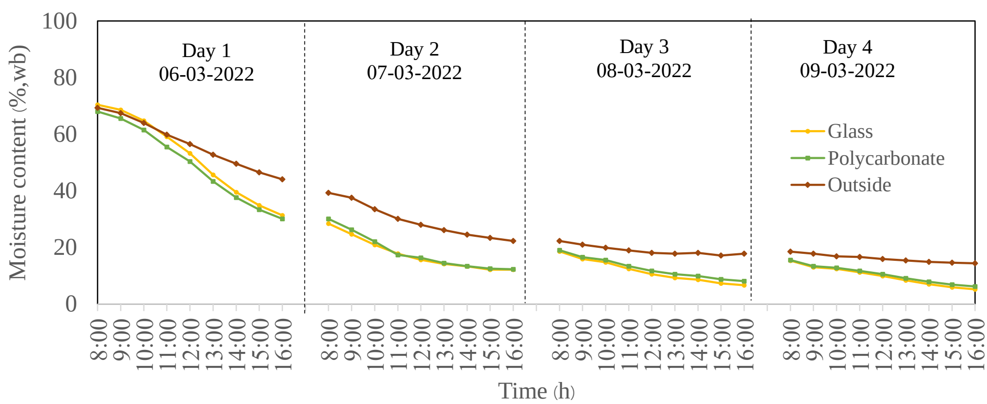

Figure 9 Comparison of moisture contents from bananas inside the two dryers and the under natural sun drying between March 6-9, 2022.

4. Conclusions

The solar dryers covered with glass sheet and polycarbonate sheet affected the temperatures inside and drying durations of banana products. The temperature inside the dryer covered with glass sheet was found higher than the dryer covered with polycarbonate sheet by 3-5°C, and also higher than the temperature outside by 25-28°C. The maximum temperatures recorded in both rounds of experiment were 68.53, 64.17, and 40.78°C for the solar dryers covered with glass sheet, polycarbonate sheet and the ambient air outside; respectively. Dried bananas in the dryer covered with glass sheet were dry more quickly than in the one covered with polycarbonate sheet. The final moisture contents in round 1 were 4.34%(wb), 5.07% (wb), and 12.01% (wb); and in Round 2 were 5.22% (wb), 6.21% (wb) and 14.37 % (wb) for the solar dryers covered with glass sheet, polycarbonate sheet and under natural sun drying; respectively. Furthermore, it was found that on day 1 and 2 of the experiments, the moisture content was quickly lost in both rounds. They were gradually reduced on days 3 and 4 in a similar way for both rounds. From the results of both rounds of the experiment, it is concluded that glass sheet can be used as a cover of dryer instead of polycarbonate. Glass was not only a material that could be found easily, but also endured with sunlight and could raise higher inside temperature than the dryer cover with polycarbonate sheet. If one only considering the time it takes to reach 12% remaining humidity attained by drying naturally under sunlight, drying bananas in glass and polycarbonate-covered dryers cuts the time required for natural drying by 42 to 45%. Finally, drying in the solar dryer not only reduces drying time but it also produces a high-quality dried product by filtrating the ultraviolet from sunlight.

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Declaration of conflicting interests

The authors declared that they have no conflicts of interest in the research, authorship, and this article's publication.

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