SNRU Journal of Science and Technology

Journal home page: snrujst.snru.ac.th

Performance of a small-scale greenhouse solar dryer for drying long peppers of Ban Khokamin Community Enterprise Loei Province, Thailand

Jagrapan Piwsaoad*, Chayapat Phusampao

Program of Physics, Department of Science, Faculty of Science and Technology, Loei Rajabhat University, Loei, 42000, Thailand

* **Corresponding Author**: Jagrapan25@gmail.com

Received: 31 January 2016; **Revised:** 28 May 2016; **Accepted:** 31 May 2016; **Available online:** July 2016

Abstract

This paper presents experimental performance of a small-scale greenhouse solar dryer for drying long peppers. The dryer consists of a polycarbonate sheets on a metal sheet floor. The dryer is 4.0 m in width, 1.0 m in length and 2.0 m in height. Four 15 W, DC fans powered by 40 W, PV module were used to ventilate the dryer. To investigate its performance, the dryer was used to dry ten batches of long peppers. For each batch, 10 kg of long peppers were dried in the dryer. Results obtained from the experiments showed that drying temperatures varied from 32 °C to 65 °C and the use of the dryer led to a considerable reduction of drying time, as compared to the open air sun drying. In addition, the quality of the product from the dryer was high-quality dried products.

Keywords: Solar energy; Small-scale greenhouse solar dryer; Long peppers

1. Introduction

Long pepper (*Piper longum* L.) is rich in essential oil containing safrole (up to 90%), a volatile constituent. Safrole is converted by the chemical industry into two important derivatives: heliotropin, which is widely used as a fragrance and flavoring agent, and piperonyl butoxide (PBO), a vital ingredient in pyrethroid insecticides. This aromatic plant offers excellent conditions for cultivation in areas with facilities for harvest, transport and industrialization. Thai Long Pepper is a tangy spice source known locally to many of the inhabitants of northern Thailand as Dee Plee, though its origins actually appeared in Europe a few hundred years ago. In Thailand, Long Pepper tree plantation areas are mainly located in northern and northeastern parts of the country. Long Pepper is an important ingredient in daily cuisine in Thailand. It is consumed both as fresh and dried products. A natural sun drying method is generally used to dry Long Pepper in Thailand; shown in Fig. 1.

With this method, substantial losses of Long Pepper due to insects, animals and rain usually occur during drying. To overcome this problem, well-performed dryers are needed to dry Long Peppers. Situated in the tropical area, Thailand receives abundant solar radiation [1]. Consequently, the use of solar dryers for long pepper drying is reasonable. Although several types of solar dryers have been developed in the last 41 years [2-4]; but, they could not meet the high demand of long peppers drying. As a result our research group has developed a small-scale greenhouse solar dryer to dry agricultural products. It was successfully used for drying fruits and vegetable [5, 6]. However, it has not been tested to dry long peppers. Therefore, the objectives of this research were to investigate the performance of the greenhouse solar dryer for drying long peppers.

Fig. 1 A natural sun drying method

2. Materials and Methods

Experiment setup

The small-scale greenhouse solar dryer was installed at Loei Province (17.48 °N, 101.72 °E), Thailand. The dryer consists of a polycarbonate sheets on a metal sheet floor. The dryer has a width of 4.0 m, length of 1.0 m and height of 2.0 m. Four DC fans operated by 40 W solar cell module were installed in the wall opposite to the air inlet to ventilate the dryer. The solar collector structure covered with polycarbonate sheets on a steel sheet floor. The solar collector is 1.0 m in width, 2.0 m in length and 0.2 m in height. The pictorial view of the dryer is shown in Fig. 2.

Fig. 2 The pictorial view of a small-scale greenhouse solar dryer

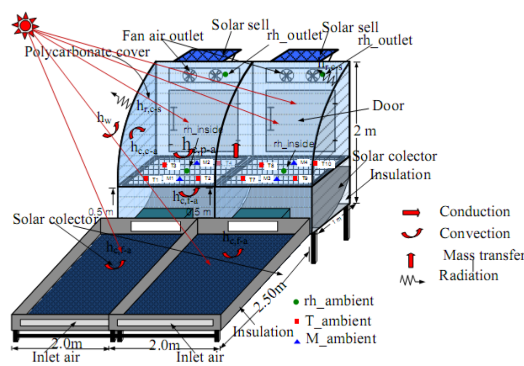

Fig. 3 Heat transfers of a small-scale greenhouse solar dryer

Solar radiation passing through the polycarbonate roof heats the air, the products inside the dryer, as well as the steel sheet floor. Ambient air is drawn in through the air inlets at the bottom of the front side of the dryer and is heated by the floor and products exposed to solar radiation. The heated air, while passing through the products, absorbs moisture from the products. Direct exposure to solar radiation of the products and the heated drying air enhance the drying rate of the products. Moist air is sucked from the dryer by the DC-fan at the top of the rear side of the dryer. Heat transfers of the dryer are shown in Fig. 3.

Experimental procedure

In this study, long peppers were dried in the small-scale greenhouse solar dryer to investigate its potentials for drying long peppers. Ten experimental runs were conducted during the period of January 2016-March 2016, and 10.0 kg of long peppers were dried for each run. Solar radiation was measured by a pyranometer (Kipp & Zonen model CMP 3, accuracy ± 0.5%) placed on the roof of the dryer. Thermocouples (K type) were used to measure air temperatures in the different positions of the dryer (accuracy ± 2%). A hot wire anemometer (Airflow, model TA5, accuracy ± 2%) was used to monitor the air speed inside the dryer. The relative humidity of ambient air and drying air was periodically measured by hygrometers (Electronnik, model EE23, accuracy ± 2%). The positions of all measurements are shown in Fig. 4.

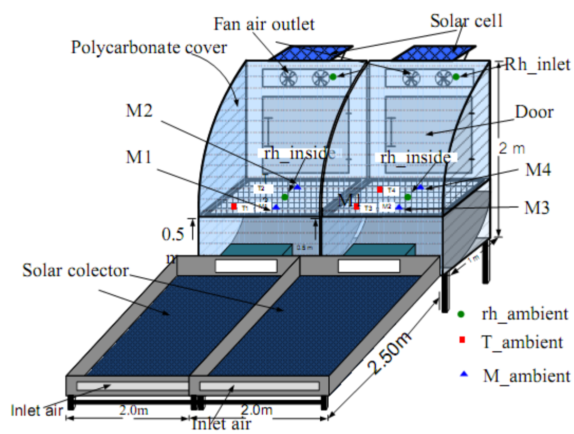

Fig. 4 The structure of the small-scale greenhouse solar dryer and the position of the thermocouples (■T), hygrometer (● rh) and product samples (▲M)

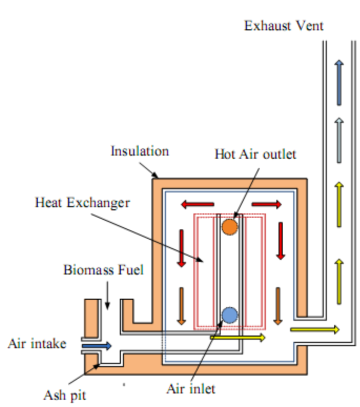

Fig. 5 The biomass stoves

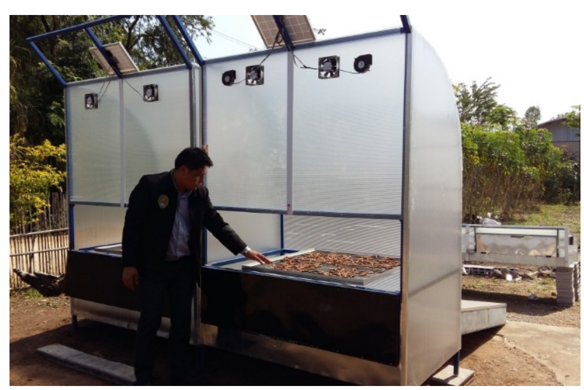

Fig. 6 Long peppers dried inside the dryer

The biomass stove increases the temperature to the small-scale greenhouse solar dryer. This works by using fuel from (wood from rubber trees) firepower. Values shown as temperatures corrected are adjusted to a temperature change (5-10 °C). This allows for comparisons between stove testes under different ambient environmental conditions. The biomass stove is 0.5 m in width, 1 m in length and 0.8 m in high. The biomass stove has a heat exchanger for heating the air. Size of the heat exchanger is 0.3 m in width, 0.5 m in length and 0.4 m in high inside the biomass stove. When the cold air outer flow into a heat exchanger at the bottom of heat exchanger and heat rises to the top of a heat exchanger and then drifted into the dryer. The structure of the biomass stove is shown in Fig. 5.

The air speed at the inlet and outlet of the dryer was recorded during the drying experiments using the hot wire anemometer. Long peppers dried in each drying test were 10.0 kg. The pictorial view of long peppers being dried in the dryer is shown in Fig. 6.

Long peppers were place on tray inside the dryer. Each day, the experiment was conducted during 8:00 am - 6:00 pm. The drying was continued on subsequent days until the desired moisture content was reached. Product samples were placed at various positions in the dryer and were weighed periodically at two-hour intervals using a digital balance. To compare the performance of the dryer with that of natural sun drying, a control sample of long peppers was placed near the dryer and dried simultaneously under the same weather conditions. The moisture content during drying was estimated from the weight of the product samples and the estimated dried solid mass of the samples. At the end of the experimental drying, the exact dry solid mass of the product samples was determined by the oven method (103 °C for 24 hours, accuracy ± 0.5%).

Economic analysis

The total capital cost for the greenhouse solar dryer (C_T) is given by the following equation, $C_T = C_m + C_l$, where C_m is the material cost of the dryer and C_l is the labor cost for the construction. The annual cost calculation method proposed by Audsley and Wheeler yields:

$$C_{annual} = (C_T + \sum_{i=1}^{N} (C_{maint,i} + C_{op,i})\ w^i)\ (\frac{w-1}{w\ (w^N - 1)}) . \quad (1)$$

where C_{annual} is the annual cost of the system. $C_{maint,i}$ and $C_{op,i}$ are the maintenance cost and the operating cost at the year *i* respectively. *w* is expressed as $w = (100 + i_{in}) / (100 + i_f)$; where i_{in} and i_f are the interest rate and the inflation rate in percent, respectively. The operating cost (C_{op}) is the labor cost for operating the dryer ($C_{labour,op}$). The maintenance cost of the first year was assumed to be 1% of the capital cost. The annual cost per unit of dried product is called the drying cost (Z, USD kg^{-1}). It can be written as: $Z = C_{annual} / M_{dry}$, where M_{dry} is the dried product obtained from this dryer per year.

$$\text{Payback period} = \frac{C_T}{M_{dry}P_d - M_f P_f - M_{dry}Z} . \quad (2)$$

where M_{dry} is annual production of dry product (kg), M_f is the amount of fresh product per year (kg), P_d is the price of the dry product (USD kg^{-1}) and P_f is the price of the fresh product (USD kg^{-1}).

3. Results and Discussion

Experimental results

Drying experiments of long peppers in the small-scale greenhouse solar dryer were carried out in 1 January 2016-20 March 2016. Ten batches of experimental run were carried out. The typical results are shown in Fig. 7 and Fig. 8.

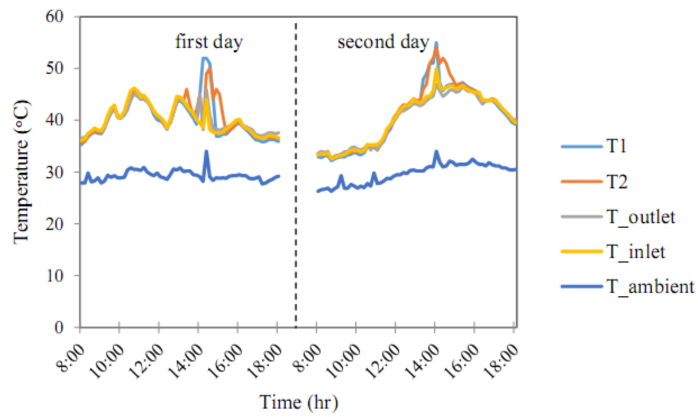

Fig. 7 Variation of ambient temperature and the temperature at different positions inside the small-scale greenhouse solar dryer

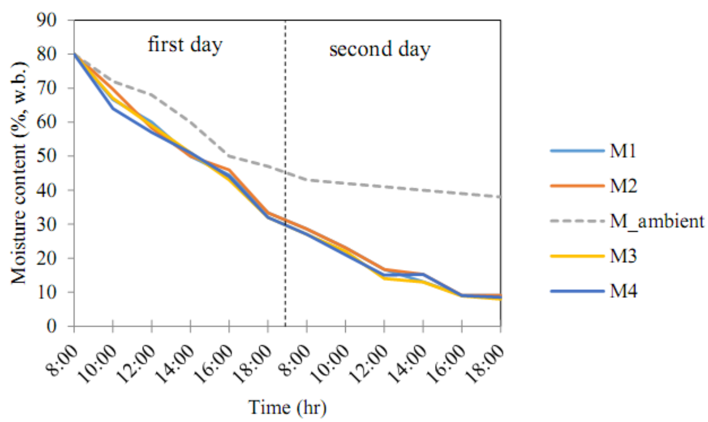

Fig. 8 Variation of the moisture contents

The comparison of air temperature at four different locations inside the dryer and the ambient air temperature for the experimental runs of solar drying of long peppers are shown in Fig. 7. The pattern of temperature change in different positions was comparable for all locations. Temperatures in different positions at these four locations varied within a narrow band. In addition, temperatures at each of the locations differed significantly from the ambient air temperature.

The comparison of moisture content at two different locations inside the dryer and the open sun drying for the experimental runs of solar drying of long peppers are shown in Fig. 8. The moisture content of long peppers in the small-scale greenhouse solar dryer was reduced from an initial value of 80% (w.b.) to a final value of 9.0-8.0% (w.b.)

within 2 days whereas the moisture content of the natural sun-dried samples was reduced to 38.0% (w.b.) in the same period.

Table 1 Data on costs and economic parameters

Items	Costs and Economic Parameters
Polycarbonate plates	600 USD
Solar modules and fans	300 USD
Materials of constructions	500 USD
Labor costs for constructions	88.9 USD
Repair and maintenance cost	1% of capital cost per year
Operating cost	171 USD per year
Price of fresh long peppers	1.70 USD kg^{-1}
Price of dried long peppers	4.25 USD kg^{-1}
Expected life of the dryer	15 years
Interest rate	1.5% (Bank of Thailand)
Inflation rate	1.0% (Bank of Thailand)

Economic evaluation

As there are now several units of this type of dryer are being used for production of dried long peppers, information used for economic evaluation is based on the field level data and recent prices of the materials used for construction of the dryers [7, 8]. Data on costs involved and economic parameters are shown in Table 1.

In term of economic evaluation, the capital cost for construction and installation of the small-scale greenhouse solar dryer is estimated to be USD 1,500 (1USD = 35.27 baht). It is estimated that 3,600 kg of dry long peppers are produced annually. Based on these production scales, capital and operating costs, the payback period of the small-scale greenhouse solar dryer for drying long peppers is estimated to be about 1 year.

4. Conclusion

Ten sets of full scale field level drying runs for drying of long peppers were conducted and the temperature of the drying air at the collector outlet varied from 34.0 °C to 65.0 °C during drying. This drier can be used to dry up to 10.0 kg of fresh long peppers. The long peppers dried in the small-scale greenhouse solar dryer were completely protected from rain, insects and dust, and the dried long peppers were a high quality product. The performance of the small-scale greenhouse solar dryer for drying long peppers has been experimentally investigated. It was found that the use of this dryer led to considerable reduction in drying time in comparison of that of sun drying. The moisture content of long peppers in the small-scale greenhouse solar dryer was reduced from an initial value of 80.0% (w.b.) to a final value of 9.0-6.0% (w.b.) within 2 days whereas the moisture content of the natural sun-dried samples was reduced to 38.0% (w.b.) in the same period. The payback period of the small-scale greenhouse solar dryer for drying long peppers is estimated to be about 1 year.

5. Acknowledgement

The authors would like to thank the Research and Development Institute of Loei Rajabhat University for the financial support provided for this research work. The authors also would like to thank Program of Physics, Department of Science, Faculty of Science and Technology, Loei Rajabhat University.

6. References

[1] S. Janjai, J. Laksanaboonsong, M. Nunes, A. Thongsathitya, Development of a method for generating operational solar radiation maps from satellite data for a tropical environmental, Sol. Energy. 78 (2005) 739-751.

[2] S. Janjai, B. K. Bala, Solar drying technology, Food Eng. Rev. 4 (2012) 16-54.

[3] A. Sharma, C. R. Chem, N. V. Lan, Solar-energy drying systems: A review, Renew. Sust. Energ. Rev. 13 (2009) 1185-1210.

[4] J.A. Duffie, W.A. Beckman, Solar Engineering of thermal Processes, John Wiley and sons, New York, 1991.

[5] M. V. Murthy, A review of new technologies, models and experimental investigation of solar dryer, Renew. Energ. Rev. (13) (2009) 835-844.

[6] S. Janjai, N. Lamlert, P. Intawee, B. Mahayothee, B.K. Bala, M. Nagle, J. Muller, Experimental and simulated performance of a PV-ventilated solar greenhouse dryer for drying of peeled longan and banana, Sol. Energy. 83 (2009) 1550-1565.

[7] E. Audsley, J. Wheeler, The annual cost of machinery calculated actual cash flows, J. Agr. Eng. Res. 23 (1978) 189-201.

[8] J. Piwsaoad, C. Phusampaoa, Greenhouse Solar Dryer for Drying Bael Fruits (*Aegle Marmelos*) in Loei Province Thailand, Proceeding of the 7th International Science, Social Sciences, Engineering and Energy Conference, Phitsanulok, Thailand, 19-21 November 2015. 721-731.