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Experimental performance of a new design of solar dryer for drying osmotically dehydrated cherry tomatoes

S. Nabnean [a], S. Janjai [b, *], S. Thepa [a], K. Sudaprasert [a], R. Songprakorp [a], B.K. Bala [b]

[a] Division of Energy Technology, School of Energy, Environment and Materials, King Mongkut's University of Technology Thonburi, Bangkok, 10140, Thailand
[b] Solar Energy Research Laboratory, Department of Physics, Faculty of Science, Silpakorn University, Nakhon Pathom, 73000, Thailand

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ABSTRACT

The performance of a new design of a solar dryer for drying osmotically dehydrated cherry tomatoes is presented. The dryer consists of drying cabinet, heat exchanger, 16-m^2 water type solar collector, and water type heat storage unit. The cabinet size is 1.0 m wide × 3.0 m long × 1.4 m high with the load capacity of 100 kg for osmotically dehydrated cherry tomatoes. Three batches of osmotically dehydrated cherry tomatoes were dried in this dryer during May–June, 2014. For each batch, 100 kg of osmotically dehydrated cherry tomatoes were dried. There was a considerable reduction in drying time in the new solar dryer as compared to natural sun drying. The dried products were completely protected from rains and insects and were of high quality dried products. The efficiencies of the solar collector was 21%–69%. The pay-back period of the dryer is estimated to be 1.37 years.

1. Introduction

Cherry tomatoes (Lycopersicon esculentum var. Cerasiforme) are a tropical fruit with high commercial value in international markets and it is an important ingredient in daily cuisine in Thailand. The production volume of cherry tomatoes in Thailand was 6840 tons in 2013 [1], and it has an annual export potential of USD 9.7 million/year.

Cherry tomatoes are consumed both as fresh and dried products. Also cherry tomatoes are highly perishable. The alternative practice for preservation of cherry tomatoes are hot air-drying with osmotic dehydration pre-treatment. The drying of cherry tomatoes with osmotic dehydration pre-treatment is not only for the preservation purpose but also for changing their texture and taste to increase marketing values.

Osmotic dehydration technique is a pre-treatment process commonly used for many tropical fruits prior to hot air-drying. According to this technique, fruits are immersing in a hypertonic solution to remove part of the water from the fruits by the osmotic process. As after the osmotic dehydration process, there are still water left in the fruits, this water is further removed by hot air-drying. For normal practice in Thailand, after the osmotic dehydration pre-treatment of cherry tomatoes, they are usually dried by natural sun drying and this method of drying has a lot of problems, as explained below.

Sun drying exposes the commodity to solar radiation and the convective power of the natural wind. Since the sun drying is a relatively slow process, considerable losses can occur. Sun drying offers a cheap method of drying but often results in inferior quality of products due to its dependence of weather conditions and the product dried with this method is vulnerable to the attack of insect infestation [2]. This process has several disadvantages like spoilage of product due to the adverse climatic condition like rain, wind, moist, and dust and loss of material due to birds and animals. Also the process is highly labour intensive, time consuming and requires large area. With industrial development, artificial mechanical drying comes into practice. However, it is highly energy intensive and expensive, which ultimately increases product cost. Thus, solar drying is the best alternative as a solution of all the drawbacks of the natural sun drying and artificial mechanical drying [3–19]. In addition, solar energy for crop drying is environmentally friendly and economically viable in the developing countries [20,21].

Many studied have been reported on solar drying of fruits [3–7,22–28]. Limited studies have been conducted on solar drying of cherry tomatoes [6,29]. However, there exist some problems associated with solar drying i.e. reliability of solar radiation during rainy period or cloudy days and its unavailability at nighttime. In a hybrid solar dryer, drying can be continued during off sunshine

* Corresponding author.
E-mail address: serm.janjai@gmail.com (S. Janjai).

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hours by back-up heat energy of stored heat. Hence the product is saved from possible deterioration by microbial infestation [30]. Variability and time-dependent characteristic of solar radiation make storage necessary for continuous operations of food drying [16,31]. Continuous drying also prevents microbial growth during drying [32]. Furthermore, it has been found that storage heat and auxiliary heat supply can be used to assess compatibility of solar energy to meet the drying process temperature [33]. Also Thailand, located in the tropical regions of Southeast Asia, gains annual average daily solar radiation of 18.2 MJm^{-2} day^{-1} [34]. Since Thailand gains relatively high solar radiation, the utilization of a solar drying technology is considered to be an alternative solution to the problem of drying osmotically dehydrated cherry tomatoes in Thailand. These factors motivated us to design a hybrid dryer.

Although limited studies have been conducted on solar drying of cherry tomatoes, no study has been reported on drying of osmotically dehydrated cherry tomatoes using hybrid dryer. There exists a research gap and literature gap on hybrid solar dryer for drying osmotically dehydrated cherry tomatoes. Therefore, the objectives of this work were to present a new solar hybrid dryer using water type solar collector, heat exchanger and solar hot water storage tank and to evaluate experimentally the performance of this new design of hybrid dryer for drying osmotically dehydrated cherry tomatoes.

2. Materials and methods

2.1. Description of the solar dryer

As the colour of cherry tomatoes are sensitive to UV solar radiation, the indirect type solar dryer was selected to dry them. Since the dryer is intended to use in a tropical region of Thailand with frequent adverse weather conditions, a thermal storage is used to overcome the problem caused by the weather conditions. The solar water heater with water storage tank was chosen because charge and discharge of thermal energy of the storage tank can be done simultaneously and fluctuation of drying air temperature can be reduced, due to high thermal inertia of the storage tank. In addition, the collector and the storage tank are commercially available with reasonable price in this country.

The proposed solar dryer consists of water type solar collector, drying cabinet, cross flow heat exchanger and heat storage unit. The schematic view of the new solar dryer is shown in Fig. 1. Hot water is circulated into the tubes of the cross flow heat exchanger where heat is transferred from the hot water to the drying air. The heated air from the heat exchanger is forced inside the cabinet dryer for drying osmotically dehydrated cherry tomatoes. The heat storage tank is used during the time when sunshine is not sufficient (Fig. 2).

The sizing of the dryer was based on an approximate calculation approach proposed by Janjai and Kaewprasert [35] as follows. The dryer was intended to dry 100 kg of osmotically dehydrated cherry tomatoes from the initial moisture content of 62% (wb) to the final moisture content of 15% (wb). As a result, the mass of water to be removed is 55.3 kg. The drying time is chosen to be 4 days. This is because longer drying time often causes spoilage due to mould and too short drying time causes case-hardening. To remove 55.3 kg of water in 4 days, the supply of heat required can be estimated from the latent heat of vaporization and mass of water removed. With the long-term average of global radiation of 18.2 MJm^{-2} day^{-1} [34], and the estimated average efficiency of solar collector of 0.5, the required solar collector area was estimated to be 9 m^2. As rain and cloudy skies usually occur for the period of 6 h, water storage tank was designed to cover the thermal energy requirement of 6 h. Therefore the storage tank of 300 L available in local market was chosen and the collector area of about 7 m^2 was added to provide thermal energy to store in the storage tank. This makes the total solar collector area of 16 m^2. Details of the design can be found in Ref. [36].

2.1.1. Water type solar collector

The water solar collector consists of transparent cover, and absorber plate. The transparent cover is a 6 mm thick clear glass supported by 70 mm aluminium frame. Absorber plate is fixed 25 mm below the glass cover. Tubes are installed to provide a water flow above the absorber plate. The total area of the solar collector is 16 m^2. It is south facing with the slope angle of 14°, the latitude of the location of the dryer. The collector efficiency evaluation is based on the temperature of the water at the inlet and outlet and incident solar radiation on the solar collector. The experiments were conducted by exposing the collector panels under the solar radiation for several days and measuring the water inlet and the outlet temperature according to ASHRAE 93-77 standard [37].

2.1.2. Heat exchanger

The heat exchanger is needed to heat the drying air from hot water coming out from the water type solar collector and the heat storage water tank. The heat exchanger used in this work (Carrier, model 42CB004) consists of tubes with hot water flowing inside the tubes and the air flowing across outside these tubes at an angle of 90°. The coil of the tubes is made of copper and it has a face area of 0.16 m^2. The fins are attached to the tubes. Each fin has the dimension of 9.0 cm × 22.5 cm × 0.025 cm. The location of the cross flow heat exchanger and the fan forcing the air is shown in Fig. 3. Heat is transferred from the hot water flowing inside the tubes to

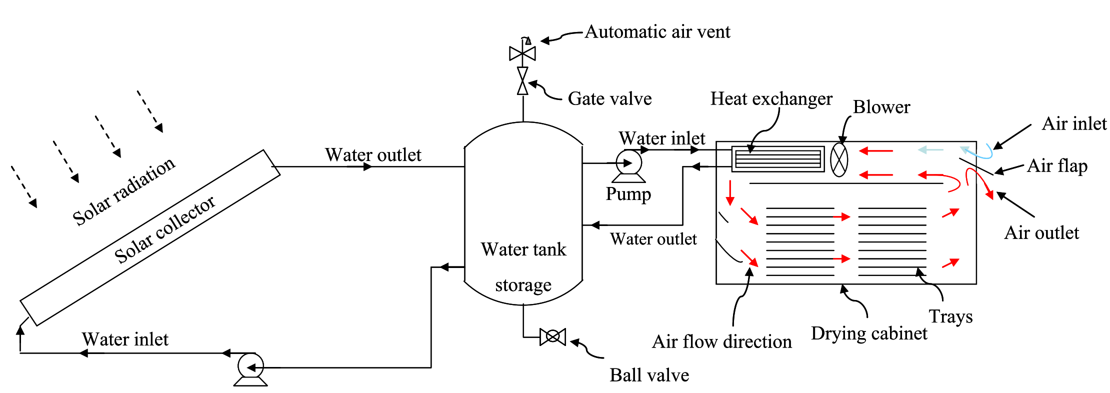

Fig. 1. Schematic diagram of the solar dryer.