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Design and performance evaluation of a new hybrid solar dryer for banana

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ABSTRACT

A hybrid solar dryer was designed and constructed using direct solar energy and a heat exchanger. The dryer consists of solar collector, reflector, heat exchanger cum heat storage unit and drying chamber. The drying chamber was located under the collector. The dryer was operated during normal sunny days as a solar dryer, and during cloudy day as a hybrid solar dryer. Drying was also carried out at night with stored heat energy in water which was collected during the time of sun-shine and with electric heaters located at water tank. The efficiency of the solar dryer was raised by recycling about 65% of the drying air in the solar dryer and exhausting a small amount of it outside the dryer. Under Mid-European summer conditions it can raise up the air temperature from 30 to 40 °C above the ambient temperature. The solar dryer was tested for drying of ripe banana slices. The capacity of the dryer was to dry about 30 kg of banana slices in 8 h in sunny day from an initial moisture content of 82% to the final moisture content of 18% (wb). In the same time it reduced to only 62% (wb) moisture content in open sun drying method. The colour, aroma and texture of the solar dried products were better than the sun drying products.

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1. Introduction

Sun drying of agricultural products is the traditional method employed in most of the developing countries. Sun drying is used to denote the exposure of a commodity to direct solar radiation and the convective power of the natural wind. Sun drying offers a cheap method of drying but often results to inferior quality of products due to its dependence of weather conditions and vulnerably to the attack of dust, dirts, rains, insects, pests, and microorganisms [1]. Solar drying is an alternative which offers several advantages over the traditional method and it has been developed for various agricultural products. Solar energy for crop drying is environmentally friendly and economically viable in the developing countries [2,3].

In natural convection solar dryers, the air flow is due to buoyancy-induced air pressure, and the drying process needs some days to complete, as a cabinet dryer needs 3–4 days to dry grapes [4]. While in forced convection solar dryers the air flow is provided by using a fan either operated by electricity/solar module or fossil fuel [5]. Some researchers are opting for forced convection solar tunnel drying for drying of various crops [6]. They reported that solar drying for grapes during the night period, it is necessary to develop a system having a back-up of thermal storage. An auxiliary heat and forced convection are recommended for assuring reliability and better control, respectively. 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 is continued during off-sunshine hours by back-up heat energy or storage heat energy. Therefore, drying is continued and the product is saved from possible deterioration by microbial infestation [7,8]. Variability and time-dependent characteristic of solar radiation make storage necessary for continuous operations of food drying [9]. The operation of a solar assisted dryer extended through the night hours and found that thermal storage during the day can be used as a heat source during the night for continuing drying of agricultural products and also preventing their re-hydration from the surrounding air [10–13]. Continuous drying also prevents microbial growth during drying [14]. Also, it was found that storage and auxiliary heat supply can used to assess compatibility of solar energy to meet the drying process temperature [15]. Misra et al. [16] reported that the advantage of storing solar heat several weeks for use in grain drying was to enable drying to proceed independently of the fall weather conditions. This allowed management flexibility in harvesting and drying the crops. The major disadvantage was that it required more hardware, in the form of a large heat storage structure and heat recovery equipment, which could lead to excessive cost.

Some hybrid dryers were developed to control the drying air conditions throughout the drying time independent of sun-shine especially at night when it is not possible to use the solar energy

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Nomenclature

$\dot{m}$	mass flow rate (kg/s)
A	surface area (m^2)
C_p	specific heat (kJ/kg K)
h_L	latent heat of vaporization (kJ/kg)
I	solar radiation (W/m^2)
Q	amount of heat energy (kJ)
t	time (h)
T	temperature (K)
η	efficiency (decimal)

Subscripts

a	air
c	collector
d	day time
f	fan
g	global
i	inlet
o	outlet
p	pump
n	night time
t	total
w	water

using alternative sawdust burner, [17] or by using a biomass stove [18]. It is reported that significant improvement was registered after the heater is added to the solar dryer during periods of low sun-shine [19,20]. Tasmparlis [21] was found that using the hybrid solar dryer connected by heating unit (20 kW) was reduced the drying time of the grapes to 30–40 h and the air velocity of 0.8 m/s produced by fan was homogeneous but small, which results in slow drying rates, hence large drying periods, also the quality for the dried fruits was very high. A solar assisted hybrid drier was developed in Asian Institute of Technology, Thailand for drying of fruits and vegetables. The drier is a tunnel type and back-up energy was provided with biomass burning during off sun-shine period [22].

Banana (*Musa sapientum* L.) is one of the important tropical fruit in the world. The ripe fruit contains many of the necessary elements that are essential for a balanced diet. Banana contains fat, natural sugars, protein, potassium and vitamins A, B complex and C. A ripe banana easily digests and it imparts quick energy. Banana can also be used as medicinal fruit. It can help recover anaemia, blood pressure, brain power, constipation, depression, hangovers, ulcer, etc. [23]. Banana is a climacteric fruit with soft texture and it becomes more vulnerable to be spoiled during transportation, preservation and marketing. Due to high moisture content in banana, it is wounded and contaminated during handling and transportation and quality is deteriorated at high temperature and relative humidity. Both qualitative and quantitative losses occur during storage through loss of moisture, carbohydrates, vitamins, pest and disease and physiological disorders [24]. Dried banana is a popular food in many countries like Thailand. The postharvest losses can be minimized by drying the ripe banana. Therefore, there is a scope of drying of banana in the tropical and subtropical countries.

An analytical model was developed for drying of sliced apple, peaches, cherries and mango in a solar cabinet dryer and in open sun drying method [25]. They were used the heat and mass balance to help in designing a solar dryer, but without using it to control the drying air conditions inside the dryer. Therefore, an improved and simplified model should be developed in this part of work.

Several studies have been reported on simulation of forced convection solar drying of agricultural products for different configurations of forced convection solar dryers [26,27].

Schirmer et al. [28] developed and tested a multi-purpose solar tunnel dryer for drying of banana under hot and humid weather conditions in Thailand. The capacity of this dryer was to dry about 300 kg of whole (not slices) ripe banana in 3–5 days. The drying temperature was 40–65 °C. They reported that solar dried banana was high quality products in terms of flavour, colour and texture. Phoungchandang and Woods [29] developed mathematical model for solar drying of whole banana in Thailand. The model agreed well with the field data. Also, the drying time by these solar dryers for banana takes some days and it needs to reduce. In addition, the quality of the dried bananas by the recent solar dryers is not high depends on the non-stability for the drying air temperature during the drying process which causes by the variation of the solar intensity during the period of sun-shine. Finally, the efficiency of the recent solar dryers not high and it needs to increase by using movable reflectors to increase the solar radiation receiving capacity.

So, the of objective of this study was to design and test continuously the hybrid solar dryer (day and night) by storing the solar energy in water tank during the sun-shine time to reduce the drying cost, improve the quality of the dried products, and to prevent the microbial growth during the drying.

Table 1
Component and specifications of the hybrid solar dryer.

Component	Specifications
1. Solar collector	
a. Type	Flat plate
b. Area	5.04 m2
c. Transparent surface	Glass, 4 mm thick
d. Absorber Plate	Corrugate sheet-metal (280 × 180 cm), 2 mm thick
f. Collector tilt	0 (horizontal)
g. Reflectors	Brilliant aluminium (180 × 80 cm), 2 mm thickness
h. Insulation	Polystyrene 50 mm thick
2. Water tank	
a. Size	500 l
b. Insulation	Made of fibre-glass, 50 mm thick
3. Water pump	
Capacity	20 l/h
4. Counter heat exchanger	
a. Type of tube	Copper (70 tubes)
b. Dimensions	180 cm length and 15 mm thick
5. Drying chamber	
a. Area	5.04 m2
b. Height	20 cm
c. Insulation	Polystyrene 50 mm thick
d. Tray	16 tray made of aluminium meshed, (90 × 70 cm)
6. Blower	
a. Type	Axial
b. Capacity	0.75 kW
7. Auxiliary Heater	
Capacity	6 kW

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