DIFFERENT TYPES OF SOLAR DRYER FOR AGRICULTURAL AND MARINE PRODUCTS: A REFERENCE GUIDE

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ABSTRACT

Drying for agricultural products are one of the most attractive and cost-effective application of solar energy. Numerous types of solar dryers have been designed and developed in various parts of the world, yielding varying degrees of technical performance. Basically, there are four types of solar dryers; (1) direct solar dryers, (2) indirect solar dryers, (3) mixed-mode dryers and (4) hybrid solar dryers. This paper is a review of these types of solar dryers with aspect to the product being dried, technical and economical aspects. The technical directions in the development of solar-assisted drying systems for agricultural produce are compact collector design, high efficiency, integrated storage, and long-life drying system. Air-based solar collectors are not the only available systems. Water-based collectors can also be used whereby water to air heat exchanger can be used. The hot air for drying of agricultural produce can be forced to flow in the water to air heat exchanger. The hot water tank acts as heat storage of the solar drying system.

***Key words**: Solar Dryer; Types of Dryer; Direct Type; Indirect Type; Mixed Mode dryer.*

INTRODUCTION

The potential of using solar energy in the agricultural sector has increased due to fluctuation in the price of fossil fuel, environmental concerns and expected epletion of conventional fossil fuels. Solar assisted drying system is one of the most attractive and promising applications of solar energy systems in tropical and subtropical countries. Traditionally all the agricultural crops were dried in the sun. Drying is one of an important post handling process of agricultural produce. It can extend shelf life of the harvested products, improve quality, improve the bargaining position of the farmer to maintain relatively constant price of his products and reduces post harvest losses and lower transportation costs since most of the water are taken out from the product during the drying process [12]. Direct sun drying requires large open space area, and very much dependent on the availability of sunshine, susceptible to contamination with foreign materials such as dusts, litters and are exposed to birds, insect and rodents. Hence, most agricultural produce that is intended to be stored must be dried first. Otherwise insects and fungi, which thrive in moist conditions, render them unusable. Other limitations were given by the availability of appropriate drying equipment which is technically and economically feasible and the lack of knowledge how to process agricultural products [6]. Up to now only a few solar dryers who meet the technical, economical and socio-economical requirements are commercially available. The technical development of solar drying systems can proceed in two directions. Firstly, simple, low power, short life, and comparatively low efficiency-drying system. Secondly, high efficiency, high power, long life expensive drying system. Various solar dryers have been developed in the past for the efficient utilization of solar energy. Many studied have been reported on solar drying of agricultural products [5]. Several studied have been done in the tropics and subtropics to develop solar dryers for agricultural products. Basically, there are four types of solar dryers; direct solar dryers, indirect solar dryers, mixed-mode dryers, and hybrid solar dryers. The energy requirement for agricultural products can be determined from the initial and final moisture content of each product.

TYPES OF SOLAR DRYING SYSTEMS: A REVIEW

A systematic classification of available solar dryers for agricultural products, based on the design of system components and mode of utilization of solar energy. Three types of solar drying systems [7]: a review

1. Natural convection solar dryers (passive dryers)

The simplest of solar cabinet dryer shown in Fig. 1. It was very simple, and consists essentially of a small wooden hot box. Dimensions of this drier is 2 m x 1 m (long and width). The sides and bottom can be portable and can be constructed from wood or metal sheet. A transparent polyethylene sheet was used as cover at upper surface. Air holes are located on the sides of the drier for circulation. A portable direct type natural convection solar dryer consists simply of a rectangular shaped with transparent top and blackened interior surfaces. Clear polyethylene plastic was placed over the heating chamber to allow solar radiation to heat the air. Black polyethylene was also placed under the chamber to absorb the heat and to keep out moisture from the ground. Another black polyethylene sheet was also placed over the drying chamber to prevent bleaching. Ventilation holes were not provided along the sides but an opening in the front of the unit allowed ambient air to enter the heating chamber and another opening at the rear of the drying chamber allowed moist air to escape from the unit. This dryer could also be used as a direct dryer for crops that are not subject to bleaching if the product is placed directly into the heating chamber. In both system, the airflow is very low and, again, the improvements did not significantly improve the performance of the dryer. Direct solar cabinet dryer fabricated and tested by Lawand [10] at the Brace Research Institute in Canada with loading of 7.5 kg/m² of drying area. The distance between the two layers of glazing is usually around 1 cm. In order to provide air circulation in the drier, air holes are located on the side of the drier. Evaluation performance studies of solar cabinet dryer were reported by [11–14]. Sharma et al. [13] found that the predicted plate temperature for no load reaches a maximum of 80–85 °C during the noon hours, while with a load of 20 kg of wheat, the maximum temperature is about 45–50 °C. As well, Minka [14] reported that temperatures reached in the cabinet dryer were 20–30 °C above ambient temperature the cabinet dryer should be useful in drying a variety of foodstuff. Gbaha et al.

[15] designed a direct type natural convection solar dryer and then tested experimentally by drying cassava, bananas and mango slices. This drying is a simple design and can be manufactured by farmers from local materials. It has a relatively moderate cost and is easy to use.

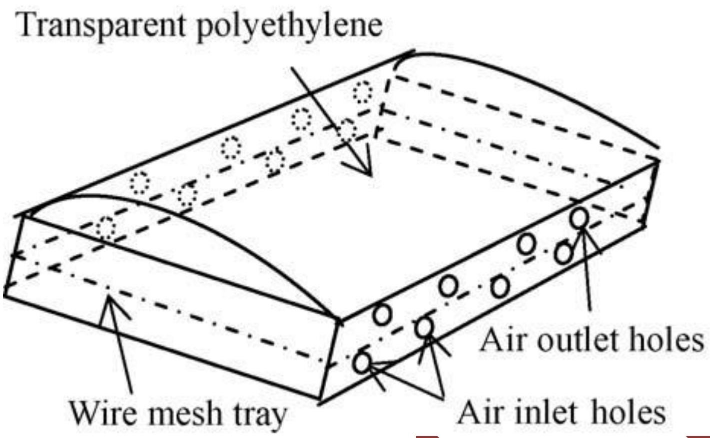

Fig. 1. Direct solar cabinet dryers.

2. Forced convection dryer (active dryers)

Direct mode forced convection dryers essentially consist of a blower to force the air through the product, a chamber, and covered with a transparent sheet. Indirect-mode forced dryers essentially consists of an air heater, drying chamber, and a blower/fan to duct the heated air to the drying chamber, illustrated in Fig. 2. It constructed and tested an indirect-mode forced dryer for drying fruit and vegetable in Iraq. The solar drying consisted of a solar collector, a blower, and a solar drying cabinet. Two identical air solar collectors having V-groove absorption plates of two air passes, a single glass cover was used. The total area of the collectors is 2.4 m². The dimensions of the drying cabinet are 1 m x 0.33 m x 2 m (width, depth, and height).

The cabinet is divided into six divisions separated by five shelves. The distance between the shelves is 0.3 m except the upper one, which is 0.5 m from the roof. Each shelf is 0.95 m x 0.3 m and is made of metallic mesh. The drying chamber walls are made of aluminum plate except the southern side, which was fixed with glass plate having the dimensions 1 m x 2m x 0.002 m. Two types of fruit and one type of vegetables were dried during the present work. These were grapes, apricots, and beans. The moisture content of apricot has been reduced from 80% to 13% within one day and a half of drying. Moreover, the moisture content of grapes has been reduced from 80% to 18% in two and a half days of drying. Finally the beans has been reduced from 65% to 18% in 1 day only. They concluded that air temperature is the most effective factor on drying rate. The effect variation of speed of air inside the drying cabinet is small and can be neglected. They also concluded that the relative humidity of air exit from the cabinet was small between (25 and 30%) and therefore there is no need for high velocity air inside the cabinet.

Solar drying system using V-groove solar collector is also developed and tested by Kadam and Samuel [22] for drying cauliflower. Its main components were galvanized iron sheet with black paint, transparent glass over it and a closed duct. The study was conducted to determine the thermal efficiency of the forced convective solar collector for drying cauliflower to obtain good quality dehydrated product. Thermal efficiency of the solar heat collector directly depends on solar radiation and humidity in the air. Karim and Hawlader [18] determined that the V-groove collector was the most efficient collector and the flat-plate collector the least efficient. It results showed that V-groove collector has 7–12% higher efficiency than flat-plate collectors. Optimum conditions of three collectors were cited to perform up to approximately 70% thermally efficient at 0.031 kg/m²s could be attained with the V-groove. The double pass operation of the collector improved the efficiency of all tree collectors. The efficiency of all the air collectors is a strong function of airflow rate. As flow rate of about 0.035 kg/m²s is considered optimal for solar drying of agricultural produce.

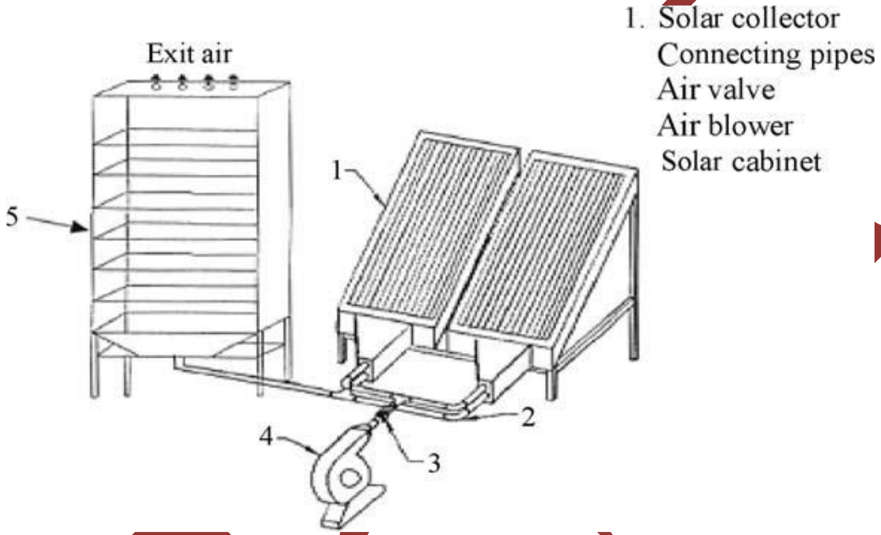

Fig. 2. Illustrate of indirect-mode forced dryer.

3. HYBRID SOLAR DRYERS

3.1. Solar drying system with thermal storage

Several workers have explored different technique for drying various agricultural products by considering the possible use of solar collector as sources of supplementary heat, and developed deep bed drying model to predict the performance. It experimentally evaluated a crop dryer cum water heater and crop dryer rock bed storage Fig. 3. They reported energy balance equations for each component of the system have been used to predict the analytical results. On the basis of the analytical results, it is observed that the drying time is significantly reduced due to the increase in thermal energy on the collector by the reflector. The system can be used to provide hot water in case the drying system is not in operation. The water heater below the air heater systems will act as a storage material for drying the crop during off-sunshine hour. Comparative performance of coriander dryer coupled to solar air heater and solar air heater-cum rock bed storage was studied by Chauhan et al. [16]. They concluded that the average moisture content of the grains in the grain bed can be reduced from 28.2%. Forced convection greenhouse solar dryer (1. solar collector, 2. blower, 3. burner stove, 4. greenhouse) [14]. Cross-sectional view of the crop dryer: (a) with cum water

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heater and (b) with rock bed storage. Cross-sectional view of the crop dryer inclined multi-pass air heater with in-built thermal storage with reflector.

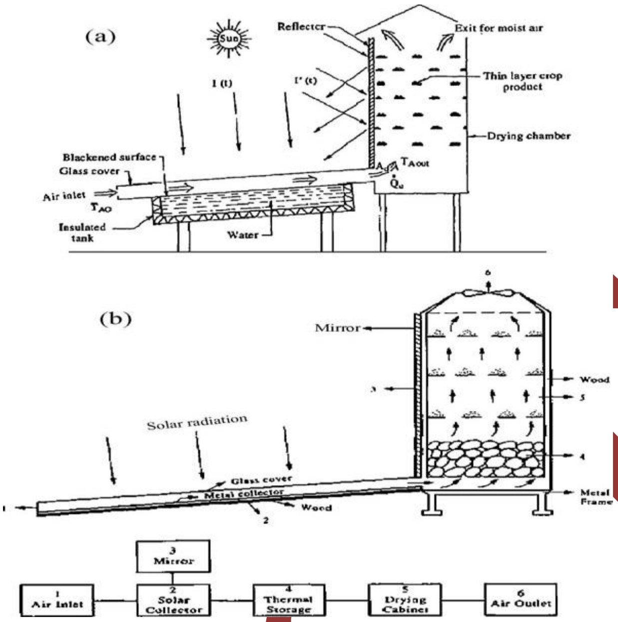

Fig. 3. Cross-sectional view of the crop dryer: (a) with cum water heater and (b) with rock bed storage.

3.2. Solar drying system with auxiliary unit

Electric heating consists of the collector, the drying chamber, fan and the auxiliary heater. Pratoto et al. to develop a simple method for sizing solar-assisted natural rubber dryers is main aim. The drying system selected being simple. The only data required are monthly average solar heat gain and monthly average drying load. The thermal performance of air collectors indicates that configuration of collector array play an important role and to estimate the system performance. They showed that an empirical relation is performed by correlating the results of short-cut simulation to design parameters which are easily determined. The development consists in relating empirically the heat savings fraction to design parameters by simulations.

Tiris et al. [12] investigated and developed a multi-rack type mixed-mode solar dryer at the Ege University, Turkey. The drying consists of the collector, the drying chamber, rack, fan and the electrical heater. The results of this study showed that the drying curves of the solar dried products were compared with traditional sun drying results. The drying periods of solar dried sultana grapes, green beans, sweet peppers and chillies were 1.8, 2.2, 1.9 and 2.0 times shorter than the natural sun dried products (drying period: 6–10 days).

3.3. Hybrid with geothermal or waste waters

Ivanova et al. [19] studied and developed the energy and economic effectiveness of a fruit and vegetable hybrid dryer at the University of Rousse, Bulgaria. The heating of the drying agent could use solar energy, geothermal or wastewaters, a conventional source, or both conventional and unconventional energy sources. Based on the experimental results, the saved energy by different schemes for energy supply is determined. Compared with the possibility of saving money from using solar energy and the heat utilized, the investment will be paid back within 2.4 years. The use of geothermal waters with temperature 68 °C secures 32.2% of the annual thermal load that has been determined to maintain the temperature of the drying agent 60 °C during day and night. The use of the solar energy during the day and hot geothermal or wastewater with temperature 68 °C during the night secures 26% of the annual thermal load.

3.4. Solar drying system with photovoltaic

The design and fabrication of the photovoltaic assisted solar drying system has been reported [15]. This drying system uses a custom designed parallel flow V-groove type collector. A fan powered by photovoltaic source assisted the airflow through the drying system. A funnel with increasing diameter towards the top with ventilator turbine is incorporated into the system to facilitate the airflow during the absence of photovoltaic energy source. The solar dryer also includes two 12 V, 1.2 A D.C.-fan attached to the intake of chimney. This drying system is designed with high efficiency and portability in mind so that it can readily be used at plantation sites where the crops are harvested or produced.

3.5. Solar drying system with heat pump

Several solar-assisted heat pump dryer have been design, fabricated and tested. Hawlader et al. [14] studied the performance of the evaporator-collector and the air collector when operated under the meteorological condition of Singapore. They showed that ''the evaporator- collector efficiency increases with increasing refrigerant mass flow rate. It was also revealed that the efficiency of the evaporator-collector is higher than that of the air collector''. The maximum efficiencies of the evaporator-collector and the air collector were found about 86% and 75% respectively.

A solar-assisted heat pump dryer was used to dry poplar and pine timbers in heat pump timber dryer were experimentally analyses. Energy and exergy analyses were made for both types of timber and the timber drying performance of the heat pump dryer was evaluated. Energy analysis was made to determine the energy utilization. Exergy analysis was accomplished to determine of exergy losses during the drying process [11]. A heat pump dryer was designed, fabricated and tested to evaluate the drying characteristics of various herbs and the dryer performance under various conditions. Fatouh et al. [8] have been reported that the heat pump assisted dryer is recommended for industrial use. The system can be used successfully over wide ranges of air flow rate and supply air temperatures for drying operations.

3.6. Solar drying system with chemical heat pump

The system consists of four mean components solar collector (evacuated tubes type), storage tank, chemical heat pump unit and dryer chamber. In this study, a cylindrical tank is selected as a storage tank. The chemical heat pump unit contains of reactor, evaporator and condenser. In the chemical heat pump a solid gas reactor coupled with a condenser or an evaporator. The general working of chemical heat pump occurs in two stages: adsorption and desorption. The adsorption stage is the cold production stage, and this is followed by the

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regeneration stage, where decomposition takes place. During the production phase, the liquid-gas transformation of ammonia produces cold at low temperature in the evaporator. At the same time, chemical reaction between the gaseous ammonia and solid would release heat of reaction at higher temperature. The incoming air is heated by condensing refrigerant (ammonia) and enters the dryer inlet at the drying condition and performs drying. After the drying process, part of the moist air stream leaving the drying chamber is diverted through the evaporator, where it is cooled, and dehumidification takes place as heat is given up to the refrigerant (ammonia). The air is then passing through the condenser where it is reheated by the condensing refrigerant and then to the drying chamber. The material dried is lemon grass.

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