Advances in Solar Assisted Drying Systems for Agricultural Produce

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Abstract: 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. The following solar assisted systems suitable for drying of various agricultural produce have been developed namely (a) the solar assisted drying systems with the V-groove collector (b) solar assisted drying systems with the double pass collector and (c) solar assisted dehumidification system (c) solar assisted chemical heat pump system and (d) photovoltaic thermal system for simultaneous production of heat and electricity.

Keywords: V-Groove Solar Collector, Double-Pass Solar Collector, Solar dehumidification system, solar assisted chemical heat pump system, photovoltaic thermal collectors

1 Introduction

Solar assisted drying system is one of the most attractive and promising applications of solar energy systems. 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.

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. The present status of post harvest drying technology for selected tropical agricultural produce is shown in Table 1 [1].

2 Air Based Solar Assisted Drying System

2.1 Solar Drying System Using the V-groove Solar Collector

Figure 1 shows the schematics of the solar drying system. The system consists of the collector, the...
drying chamber, fan and the auxiliary heater. The solar collector is of the V-groove type and the collector area is about 15 m². An average output temperature of 50 °C can be achieved with a flow rate of 15.1 m³/min and an average solar radiation of 700 W/m² and ambient temperature of 27 – 30 °C. Experimental studies on the performance of a solar assisted drying system on herbal tea, chilies, and noodles have been conducted. Hot air is discharged into the drying chamber from outlet duct, which is strategically located for optimum performance. A 10 kW auxiliary heat source has been used for continuous operation and more effective temperature control [2 - 3].

![Figure 1: Schematics of the solar assisted drying system with the V-Groove Collector](image)

Herbal tea or green tea contains many organic compounds and the processing requirements differ depending on specifications on the types of tea to be produced. Discoloration of herbal tea will occur if the drying process is delayed. Fresh tealeaves have an initial moisture content of 87% (wet basis). Drying is required to lower the final moisture content of 54 % (wet basis). This will allow the green color of the tea to be maintained. The auxiliary heater is on if the drying chamber temperature is below 50 °C. The flow rate is fixed at 15.1 m³/min. The initial weight of the fresh tealeaves is 10.03 kg and the final weight is 2.86 kg. Figure 2 shows the energy requirement for the drying process of herbal tea. The drying process started at 8:00 and ended at 18:00. The total energy required to maintain a drying chamber temperature of 50 °C is 60.2 kWh. The auxiliary energy contribution is 17.6 kWh. Hence, solar energy contributes 42.6 kWh during the process and contributes approximately 70.2 % of the overall energy requirement. To further decrease the weight to 2.86 kg, further drying is required. The drying process is continued until 20:00 and the contribution of solar energy in the total energy requirement dropped to 56.3 %.

![Figure 2: The contribution of the auxiliary and solar energy to maintain the drying temperature at 50 °C and average solar radiation level of 567.4 W/m²](image)

2.2 Solar Drying System Using the Double-Pass Collector with Integrated Storage System

Figure 3 shows the double-pass type solar collector. The second or lower channel of the solar collector is filled up with porous media which acts as heat storage system. This will increase the outlet temperature and the performance of the system [4 – 6]. The collector width and length are 120 cm and 240 cm. The upper channel depth is 3.5 cm and the lower depth is 10.5 cm.

![Figure 3: The schematic of a double-pass solar collector with porous media in the second channel](image)

The system was tested for the drying of oil palm frond chips. Malaysia is the world's largest producer and exporter of palm oil and accounts for more than 60% of global export. Palm oil is
extracted from oil palm fruits in the mills. The waste products of oil palm mills are empty fruit bunches, fibers, shells and fronds. There are about 145 oil palm trees per hectare in Malaysia. About 25 pieces of fronds can be obtained from a single tree. The average weight of each frond is about 8 kg. Hence, about 200 kg of fronds can be obtained in a year per tree. Hence, about 30 tons of fronds can be produced in one hectare in a year. Some of the palm fronds have to be cut to facilitate the harvesting of the fruit bunches. The fronds can be converted into useful products. One way is to chip and then dry them to be used as feedstock for animal feed.

The solar drying system consists of solar air collector, blower, auxiliary-heater and drying chamber. The auxiliary heater is equipped with an on/off controller. The set temperature is 50°C based on the temperature of the inlet to the drying chamber. Arranging this type of collector is not as simple as the V-Groove single pass collector. The collector arrangement is shown in Figure 4.

The collector width and length were 120 cm and 240 cm respectively. The upper channel depth is 3.5 cm and the lower depth is 10.5 cm. The bottom and sides of the collector have been insulated with 5 cm thick fiberglass to minimize heat losses. The solar collector array consists of 6 solar collectors (A1 – A3 and B1 – B3), arranged as 2 banks (A and B). Each bank (A and B) has three collectors connected in series. Air enters the two inlets of the upper channel of collectors A1 and B1 and flows in the lower channel of collectors A1 and B1. The air flows to collectors A2 and B2 through the internal manifolding connecting collectors A1-A2 and B1-B2. Next, the hot air enters collectors A3 and B3. Finally, the hot air from the two banks of collectors (A and B) were mixed and induced by a centrifugal blower to a common outlet and directed to drying chamber.

The system has been designed for drying of wet ground fronds from moisture content of 60% wet basis to 10% weight product and the drying time is not more than 10 hours. The blower power rating was 0.11 kW, 230V rotating at 2520 RPM. The collector was tilted at 15° from the horizon. Figure 5(a) and 5(b) show the resulting outlet temperature if the flow rate is fixed at 0.0995 kg/s. The outlet temperature is about 90°C at an average solar radiation level between 900 - 1000 W/m² as well as the performance of the system.

![Figure 4 The collector arrangement for the solar drying system.](image)

The outlet temperature does not drop drastically as in any conventional solar air collector. The outlet temperature goes down gradually in the evening even at low solar radiation levels. The reason for this is because of the presence of the porous media in the second channel that acts as the heat storage media for the system.

![Figure 5 The thermal efficiency of the system](image)
conditions, especially in the morning and the evening.

2.3 Solar Drying System with Photovoltaic Thermal Collectors

The application of solar energy can be broadly classified into two categories; thermal energy systems which converts solar energy into thermal energy and photovoltaics energy system which converts solar energy into electrical energy. The vital component in solar energy system is the solar collections systems. Two solar energy collection systems commonly used are the flat plate collectors and photovoltaic cells. Normally, these two collection systems are used separately. It has been shown that these two systems can be combined together in a hybrid photovoltaic thermal (PVT) energy system. The term PVT refers to solar thermal collectors that use PV cells as an integral part of the absorber plate. The system generates both thermal and electrical energy simultaneously. The number of the photovoltaic cells in the system can be adjusted according to the local load demands. In conventional solar thermal system, external electrical energy is required to circulate the working fluid through the system. The need for an external electrical source can be eliminated by using this hybrid system. With a suitable design, one can produces a self-sufficient solar collector system that required no external electrical energy to run the system [7 -9].

The technical development of the air cooled PVT systems can proceed in two directions. Firstly, simple single passed with photovoltaic panel as the absorber plate and relatively low combined photovoltaic thermal efficiency. Secondly, high efficiency, multiple-pass with some heat transfer augmentation features. The double-pass flow enhanced cooling of the photovoltaic cells and thus increasing the efficiency of the systems.

The double-pass concepts was later extended to include heat transfer augmentation features such as a fins for enhancing heat removal by convective and conductive heat transfers and also compound parabolic collectors for solar radiation booster. The performance of the double-pass solar collector can be further increased by including these features. The intensity of the solar radiation incident upon the photovoltaic panel can be increase by installing a booster concentrator. Figure 6 shows the basic design of the double-pass photovoltaic thermal solar collector with compound parabolic concentrator (CPC) and fins. The air flowed through the first channel formed by the glass cover and the photovoltaic panel. Next it enters the second channel formed by the back plate and the photovoltaic panel. The first channel has compound parabolic concentrators to concentrate solar radiation. The second channel has fins that transfer the heat from the photovoltaic panel. This flow arrangement and the compound parabolic concentrators as well as the fins will increase heat removal from the photovoltaic panel and will enhance the efficiency of the system. The concentration ratio (CR) is = 1.86. Figure 7 shows the performance of various PVT including single, double-pass system, double pass with compound parabolic solar collector and fins.

![Diagram of double-pass photovoltaic thermal solar collector](image1)

![Diagram of double-pass photovoltaic thermal solar collector with compound parabolic and fins](image2)

Figure 6: Double-pass photovoltaic thermal solar collectors system with (a) fins and (b) CPC and fins

![Graph showing overall performance](image3)

Figure 7: Overall performance of photovoltaic thermal solar collector with single, double-pass system, double pass with compound parabolic solar collector and fins
3 Water Based Solar Assisted Drying System

3.1 Solar Drying System with Chemical Heat Pump

The schematics of a solar-assisted chemical heat is shown in Figure 8 [10]. 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 reactor contains a salt which reacts with the gas, the reactions used in this study is:

\[ \text{CaCl}_2 \cdot 2\text{NH}_3 + 6\text{NH}_3 \rightarrow \text{CaCl}_2 \cdot 8\text{NH}_3 + 6\Delta H_r \]

The drying chamber contains multiple trays to hold the drying material and expose it to the air flow. 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 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.

3.2 Solar Assisted Dehumidification System

The temperature of air in drying process affects the quality, evaporation capacity as well as drying period. In addition, shorted time period is required for higher temperature drying. At higher temperature, pure water vapor pressure becomes higher; therefore, the difference between water vapor partial pressure and pure water vapor pressure becomes higher. This pressure difference is the driving force of water evaporation to the air. This driving force is directly proportional to the evaporation rate of water to air. However, drying at high temperature is not suitable for the materials which are sensitive to heat because it can cause cracks, browning which further reduce the taste of final product as well as the evaporation of the active ingredients such as in medicinal herbs.

A solar dehumidification system for medicinal herbs has been developed as shown in Figure 9. The system consists of a solar collector, an energy storage tank, auxiliary heater, adsorbent, water to air heat exchanger, a water circulating pump, drying chamber, and other equipment. It is made up of essentially three processes, namely regeneration, dehumidification, and batch drying. During regeneration process, the air outside the dryer is heated with the heat exchanger and is supplied to the adsorbent. The adsorbent is heated with this hot air and water content rate is reduced, removing the water content. The water content is evaporated by the hot air and leaves the dryer. During dehumidification (adsorption) process, the air inside the dryer passes through the heat exchanger by use of the blower. However, since no hot water is circulated in the heat exchanger, the air reaches the adsorbent. The air is dehumidified with the adsorbent and is supplied the drying load as the dry air. The relative humidity and temperature of the drying chamber are 40% and 35 C respectively.

![Figure 8 Schematic diagram of solar assisted chemical heat pump dryer](image)

![Figure 9 Solar assisted dehumidification system](image)
4. Conclusions

Drying is one of the oldest and most important preservation methods for reduction of moisture content of foods or other heat sensitive, biologically active products. Beside removal of water the quality of the dried product must be taken into consideration. The quality of the products depends on many factors including the drying temperature and duration of drying time. Some product such as medicinal herbs requires low temperature to prevent the active volatile essential ingredient from being removed during conventional high temperature drying.

Solar assisted drying system is very environment friendly and will enhance energy conservation. However, one of the main disadvantages of solar energy system is the problem associated with the intermittent nature of solar radiation and the low intensities of solar radiation in solar thermal systems. Hence, many innovative ways of using solar assisted systems for drying of agricultural produce. In both air based and water based system, the new solar collector and the storage system designs are essential for increasing the performance of the system. The systems developed and presented in this paper have the advantages of heat storage, auxiliary energy source, integrated structure control system and can be use for a wide range of agricultural produce.

References:


