Studies of A Photovoltaic-Thermal Solar Drying System For Rural Applications

MOHD. YUSOF OTHMAN, BAHARUDIN YATIM, KAMARUZZAMAN SOPIAN, AZAMI ZAHARIM AND MOHD. NAZARI ABU BAKAR
Solar Energy Research Institute
Universiti Kebangsaan Malaysia
43600 Bangi Selangor
MALAYSIA

Abstract: Importance of solar drying is increasing worldwide, especially in areas where the use of the abundant, renewable and clean solar energy is essentially advantageous. In the developing countries and in rural areas the traditional open-air drying methods should be substituted by the more effective and more economic solar drying technologies. In the present work, a new design of a photovoltaic-thermal (PV/T) solar drying system was fabricated. An experimental study of PV/T solar air collector has been performed towards achieving an efficient design of air collector suitable for a solar dryer. A series of experiments were conducted based on the ASHRAE standard, under Malaysia Climatic conditions. The performance of the collector is examined over a wide range of operating conditions. Results of the test are presented and discussed.

1 Introduction
One of the most important potential applications of solar energy is the solar drying of agricultural product. Losses of fruits and vegetables in developing countries are estimated to be 30% to 40% of production [1]. The post-harvest losses of agricultural products in the rural areas of developing countries can be reduced drastically by using well-designed solar drying systems. Since the air collector is the most important component of a solar food drying system, improvement of the design of collectors would lead to better performance of the system.

Solar air collectors, although a very important component in the solar drying system, have not received much attention unlike solar liquid collectors [2]. Several designs of solar air collectors have been studied over the years. The design of suitable air collectors is one of the most important factors controlling the economic of solar drying. As of now, flat plate solar collectors are widely used. Air may be allowed to flow above, below or on both sides of the absorber plate. The concept of a double pass solar air heater was introduced by Satcunanathan and Deonaraine [3] to reduce the cover losses. They have shown experimentally the superiority of the performance of the double pass air heater over the single pass.

Air type solar collectors have two inherent disadvantages; low thermal capacity of air and low absorber to air heat transfer coefficient. Different modifications are suggested and applied to improve the heat transfer coefficient between the absorber plate and air. These modifications include the used of an absorber with fins attached [4,5], corrugated absorber [6,7] and matrix type absorber [8]. The literature reported higher efficiency of V-grove and finned collectors without significantly increasing pressure drop. The studies reported higher efficiency of a matrix collector but also reported higher power consumption due to increased pressure drop across the matrix [9]. Another alternative methods of producing high efficient solar energy conversion system is the photovoltaic-thermal solar collector or hybrid solar collector. The collector converts solar radiation into both thermal and electrical energies simultaneously.

In the present work, a new design of a double pass photovoltaic-thermal solar air collector with compound parabolic concentrator (CPC) and fins has been studied. The collector was fabricated and purposely designed for solar drying system application. The collector design concept and the collector array are shown in Fig. 1 and Fig. 2.
The collector is tilted at 14° from the horizon and facing south. The array consists of two type of collectors, photovoltaic-thermal collector and flat plate solar thermal collector in series. Air enters the first collector through the upper channel formed by the glass cover, CPC and the photovoltaic panel. Next it enters the lower channel of the collector formed by the back plate and the photovoltaic panel. The hot air from the first collector then enters the second collector through the upper channel formed by the glass cover and the absorber plate followed by the lower channel of the second collector before it goes to the drying cabinet as shown in Fig. 3.

Fig. 2: The collector array for the solar drying system.

2 Instrumentation
The measured variables in the experiment include inlet and outlet air temperatures, ambient temperature, temperatures at several locations, current, voltage, air flow rates, wind velocity and the solar radiation incident on the collector plane.

The system were instrumented with K-type thermocouples for measuring temperatures. An Appley pyranometer was used to measure the solar radiation in the plane of the collector. A flow meter with an electronic transducer was used to measured the wind velocity. The air flow rate was calculated from the air velocity measured by a vane type anemometer at the collector outlet and the known duct area. The weight change of the dried material was measured by digital balance and connected direct to the computer. The current generated from the collector and the corresponding output voltage were also measured, so that the power consumption of the fans can be computed. All the sensors used in the collector and drying cabinet were continuously monitored and output signals were recorded in a data acquisition system.

3 Material and Methods
The solar air collector performance evaluation is important for optimal sizing of collectors for a given task. The unpredictable nature of parameters involved in solar systems is the major obstruction for an exact theoretical study. For solar applications, experimental study is very important to determine the actual performance of the system under the meteorological conditions of the place of interest. In the present study, solar air collector tests have been
performed under the meteorological conditions of University Kebangsaan Malaysia.

The size of the collector was selected based on previous results of the laboratory investigations conducted under controlled conditions. The overall dimension of the collector is chosen to be 2.44 m in length, 1.51 m in width and 0.215 m in height. It consists of 72 solar cells, CPC with 1.86 concentration ratio and series of fins attached to the back of the absorber surface. The dimension of the dryer is chosen to be 1.10 m x 0.60 m x 0.80 m (length x width x height). It consists of wire mesh strays and 4 small dc fans powered by PV/T collector located on the roof top. The fans were installed at the inlet duct of the dryer to ensure continuous ventilation by sucking the hot air from the collector into the dryer.

Collector performance were conducted on days with a clear sky condition. Paired tests were conducted to determine the repeatability and reliability of the results. The data acquisition system collected the necessary data every 20 s and recorded the averaged data every 1 minute interval during the while drying process.

4 Results And Discussions

High levels of incident solar energy is recorded during the whole year. A maximum global radiation of about 1000 W/m² is measured during the mid-day. The course of the air temperature in the solar air heater is mainly influenced by the collector design, material used as cover and absorber, solar radiation, ambient temperature, humidity and air flow rate. The global solar radiation resulted in an increase of the drying air temperature inside the collector to reach a maximum value of about 72°C at peak conditions as shown in Fig. 4. The inlet and outlet temperature were varied accordingly to the solar radiation level. The temperature difference between the ambient and the collector outlet measured during the mid-day was about 33°C.

The performance parameters of the hybrid PV/T collector are obtained in terms of the electrical and thermal efficiency. The combined photovoltaic-thermal efficiency of the system is the sum of photovoltaic and thermal efficiencies of the system [10].

\[
\eta_{\text{PVT}} = \frac{\dot{m}C_f \int_{t_i}^{t_f} (T_o - T_i) \, dt + \int_{t_i}^{t_f} P_E \, dt}{(CR)A_c \int_{t_i}^{t_f} S \, dt}
\]  

(2)

Where \( \dot{m} \) is the mass flow rate (kg/s), \( C_f \) is the fluid specific heat (J/kgK), \( S \) is the incident solar radiation (W/m²), \( A_c \) is the collector aperture area (m²), \( T_i \) Temperature at the end of the first collector and \( T_o \) is the fluid inlet and outlet temperature (°C) and CR is the concentration ratio of the CPC. Fig. 6 shows the

Fig. 4: Global radiation, ambient temperature, collector inlet and outlet temperature versus time of the day.

Fig. 5: The variation of the short circuit current (\( I_{sc} \)) and open circuit voltage (\( V_{oc} \)) for the day. The increase of solar radiation levels will effect the short circuit current and open circuit voltage of the collector.
variation of measured data and the combined efficiency obtained throughout the day. The mass flow rate varies from 0.012 kg/s to 0.027 kg/s resulting the combined efficiency of the collector varies between 25% to 50% at peak conditions.

Fig. 5 : Variation of solar radiation with the resulting open circuit voltage Voc and short circuit current Isc

Fig. 6: Variation of solar radiation of the day with the resulting combined efficiency of the system.

Drying experiments were conducted when fans were powered by PV/T solar collector. Under this condition the air flow rate is found to be varied with the levels of solar radiation. At high incident solar radiation, more energy is received by the collector absorber plate which is resulted in increasing the air temperature inside the collector.

Fig. 7: Temperature rise inside the collector at various incident radiation levels

On the other hand, the increase of the temperature is compensated by the increase of the air flow rate inside the outlet duct since the output power of the solar module is increased with the increase of the incident solar radiation. To assess the performance of the solar collector the temperature difference between the collector inlet and outlet versus incident radiation is studied and illustrated in Fig. 7. The temperature rise inside the dryer is found to be directly proportional to the incident radiation on the collector surface. The drying experiments revealed that the drying process can be achieved within the same day depending on slice thickness, loading capacity and above all solar radiation levels. Fig. 8 shows the variation of moisture content of 5 mm thick sliced mangoes obtained from the PV/T drying system.

Fig. 8: Variation of moisture content of sliced mangoes during solar drying process

5 Conclusions
The photovoltaic-thermal solar drying system was successfully tested under the field conditions of University Kebangsaan Malaysia where high quality
product is obtained. The dryer can be easily constructed with simple tools and low labour. Loading and unloading the dryer is found to be quite easy and the maintenance can be done by the farmers themselves. The performance of the solar collector to heat the drying air is assumed satisfactory. The quality attributes such as colour, flavour, taste is significantly improved since it is protected from rain, dust, insects etc., in contrast to sun drying. The method of driving the fans by the solar module of PV/T collector is assumed to be suitable and appropriate for the use in the remote rural areas where no power supply from the grid is available.

Acknowledgements

The authors would like to thank the Ministry of Science, Technology and the Environment Malaysia for sponsoring this work under project IRPA 02-02-02-0007-EA109

References: