Renewable and Sustainable Energy Reviews 90 (2018) 142–159

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

PVT air collector integrated greenhouse dryers

Sumit Tiwari[a,*], Sanjay Agrawal[b], G.N. Tiwari[c]

[a] Centre for Energy Studies, Indian Institute of Technology Delhi, Hauzkhas, New Delhi 110016, India
[b] School of Engineering and Technology, IGNOU, New Delhi 110068, India
[c] Bag Energy Research Society (BERS), Sodha Bers Complex, Plot No. 51, Mahamana Nagar, Karaudi, Varanasi, UP, India

ARTICLE INFO

Keywords:
Energy
Exergy
PVT air collector
Thermal modelling

ABSTRACT

The development of cleaner and renewable energy sources are necessary so that fossil fuel dependency and global warming can be reduced. Present communication is an attempt to explore the available literature on Photovoltaic Thermal (PVT) air collectors and PVT air collector integrated greenhouse drying system. Solar drying is one of the best method to preserve crops for a long time. In developing and under developed countries; per capita electricity production is low; therefore the electricity uses for heating purpose cannot be economically and environmentally justified option. In previous studies, it was found that forced drying is better in terms of controlling drying parameters and PVT air collector is better than standalone PV module in terms of energy storage. In present review paper, combination of PVT air collector and drying system has been discussed. Moreover, thermal modelling of PVT air collector integrated greenhouse drying system has been presented in detail. Average thermal efficiency, electrical efficiency and overall thermal efficiency for PVT air collector are found to be 26.68%, 11.26% and 56.30% respectively at 0.01 kg/s mass flow rate of air. This review paper may be very helpful for researchers and scientists to develop thermal models for different hybrid solar systems.

1. Introduction

The depletion of fossil fuels and climate change are two problems that need to be addressed in every sector of life. Energy demand is enhancing rapidly since the starting of industrialization and cause the environmental deterioration. Therefore, the developments of renewable and clean energy are necessity of present society. Solar drying system can be considered as one of the clean and renewable technology which can reduce the fossil fuel dependency and global warming. Among all food preservation techniques, sun drying is a one of the oldest and economical method. Open sun drying has been utilized since older time for drying of wood, fruits, fish, plants, seeds, meat and other agricultural produce for preservation [1]. Open sun drying contains many limitations like, insect infestation, decolouration, degradation due to microbiological reactions, least control on the drying parameters, and so on. Fruits like apricots, figs, plums, saffron, peaches and grapes have been dehydrated over centuries, but in recent times some other cultivated products like pineapple, apples, banana, mango and pears have also been gaining importance [2]. Further, the quality of dried agricultural products has been increased by introducing solar drying systems. Solar dryers can be broadly classified into natural mode and forced mode based on their operational conditions. Many researchers concluded that drying under forced mode is better than the natural mode in terms of controlling drying parameters [3,4]. The performance of drying system depends on solar energy collection in the system which can be enhance with the help of flat plate air collector.

Double passes packed bed solar air heaters have been discussed by Singh and Dhiman [5]. It was concluded that the double air pass packed bed solar air heater give enhanced performance in comparison to the single pass packed bed solar air heaters theoretically and experimentally in both modes of flow, parallel and counter. An air collector with glazed hybrid photovoltaic thermal (PVT) module was studied by Agrawal and Tiwari [6]. It was found that hybrid system gives a larger potential (in terms of energy) compared to stand alone PV module. Further, the annual overall thermal exergy and energy gains were found to be 289.5 kWh and 1252.0 kWh respectively. Enviroeconomic analysis and the energy matrices based on glazed hybrid PVT module air collector were calculated [7]. Tiwari et al. [8] developed a novel hybrid PVT greenhouse solar drying system. Thermal modelling with experimental validation was done and values of overall thermal energy found to be 2.03 kWh experimentally. The Performance analysis of glazed PVT air collector has been carried out and found that there is a substantial reduction in annualized uniform cost caused by earning carbon credit [9]. Relative study of the climate condition of Srinagar was done on different type of PVT air collector namely, conventional hybrid PVT, glazed and unglazed hybrid PVT tiles air collectors [10]. The

* Corresponding author.
E-mail address: tiwsumit@hotmail.com (S. Tiwari).

https://doi.org/10.1016/j.rser.2018.03.043
Received 14 June 2017; Received in revised form 17 October 2017; Accepted 17 March 2018

Nomenclature

A_c	Area of the crop surface (m^2)
A_{cf}	Opening area of fan (m^2)
A_{c1}	Cross-sectional area of duct of air collector (m^2)
A_m	Area of the PV module (m^2)
A_w	Area of side walls of dryer (m^2)
A_t	Area of the tray (m^2)
C_f	Specific heat of air (J/kg K)
C_{cr}	Specific heat of crop (J/kg K)
d	Diameter of DC fan (m)
E_{el}	Electrical energy (kWh)
hi	Heat transfer coefficient inside PVT air collector and solar drying system (W/m^2K)
h_{crr}	Total heat transfer coefficient from crop surface to drying chamber (W/m^2K)
h_{crc}	Convective heat transfer coefficient from crop surface to drying chamber (W/m^2K)
h_{crew} or h_{ew}	Evaporative heat transfer coefficient from crop surface to drying chamber (W/m^2K)
h_o	Heat transfer coefficient from top of module to ambient air (W/m^2K)
h_{pf}	Heat transfer coefficient from absorbing plate to working fluid (W/m^2K)
I_t	Solar intensity (W/m^2)
I_w	Total solar intensity on the walls of drying chamber (W/m^2)
K_g	Thermal conductivity of glazing (W/mK)
L_g	Thickness of the glass (m)
-	Mass flow rate of working fluid (air) (kg/s)
M_{cr}	Mass of crop (kg)
P_{Tr}	Partial pressure at green house chamber temperature (N/m^2)
P_{Tcr}	Partial pressure at crop temperature (N/m^2)
T_a	Ambient temperature (°C)
T_o	Cell temperature for optimum cell efficiency
T_c	Cell temperature (°C)
T_{cr}	Crop temperature (°C)
T_{cro}	Initial crop temperature (°C)
T_r	Drying chamber temperature (°C)
T_{fo}	Air temperature at outlet of PVT air collector (°C)
U_{bcf}	Heat transfer coefficient from bottom of module to working fluid (W/m^2K)
U_{tca}	Heat transfer coefficient from top of module to ambient air (W/m^2K)
U_{bpa}	Heat transfer coefficient from bottom of absorbing plate to ambient air (W/m^2K)
Q_{th}	Thermal energy (kWh)
$Q_{ov,th}$	Equivalent thermal energy (kWh)
$Q_{th,ex}$	Thermal exergy (kWh)
α_c	Absorptivity of solar cell
α_{cr}	Absorptivity of crop
β_0	Temperature dependent efficiency factor
β_c	Packing factor of module
γ	Relative humidity
η_0	Standard efficiency at standard condition
η_c	Solar cell efficiency
η_m	Module efficiency
η_{th}	Thermal efficiency
η_{el}	Electrical efficiency
$\eta_{eq,th}$	Equivalent thermal efficiency
η_{ex}	Exergy efficiency
$\eta_{ov,ex}$	Equivalent exergy efficiency
v	Wind velocity in ambient (m/s)
v_1	Air velocity in duct of air collector (m/s)
v_2	Air velocity from fan (m/s)
v_3	Air velocity in drying chamber (m/s)
τ_g	Transitivity of glass

greenhouse dryers were investigated under forced convection mode as well as natural mode. Forced and natural mode found to be best for low moisture content crops and high moisture content crops respectively. In Southeast Asian countries, PV integrated solar greenhouse dryers are most applicable drying system for crop drying in commercial scale [11]. Shalaby et al. [12] studied phase change material (PCM) as a heat storing medium. It was found that the solar drying system with PCM decreases the heat transfer outside the system and consequently increases performance of the system. Moreover, various techniques were investigated which have been used to increase the thermal conductivity of the used PCM. Mustayen et al. [13] reviewed numerous types of solar based drying system on the basis of design, performance, and application which includes mixed-mode, indirect, direct, passive and active solar dryers. The best results have been debated to resolve the difficulties related to conventional drying. PCM plays a vital part in energy saving and consequently increasing the reliability of the solar drying systems by smoothening the output for uninterrupted drying of crops [14]. The development of various models of drying was drawn from the earlier descriptions sorption and moisture equilibrium models for the deep bed and thin layer drying analysis [15]. Further, dissimilar empirical relations for particular crops and circumstances were investigated for improved forecasts. Sharma et al. [16] discussed a comprehensive review of the numerous designs, construction and working principles of the extensive diversity of solar drying systems. The authors determined low budget, crop drying techniques with the help of solar energy which can be introduced to enhance overall processing hygiene, reduce spoilage, and improve product quality for rural areas. This can also considerably increase the agricultural incomes for agriculturalists. Fudholi et al. [17] were talking over marine and agricultural products for solar drying and concluded that it has an enormous prospective from energy saving perspective. Further, technical advices were given to develop solar drying systems for crops having high efficiency, compact design, long-life and integrated storage. Various mathematical modelling and performance evaluation has been discussed on the basis of characteristic curves for greenhouse drying system [18,19]. Work carried out on solar dryer working under forced mode has also been listed in Table 1.

1.1. Objective

Objective of present paper are as follows:

a. Present paper is concentrated on study of (i) PVT air collector and (ii) PVT air collector integrated greenhouse drying system.
b. The present study is taken to promote self- sustaining solar systems so that solar system under forced mode can be used in rural areas where grid connectivity is not available.
c. The present study is also useful because the maximum allowable temperature of every crop (Table 2) is different, temperature of the greenhouse can be varied through changing the mass flow rate.

2. PVT air collector and PVT integrated solar drying systems

The hybrid PVT collector is system which are built for best use of the solar energy to generate not only electricity but also heat from a single PV module. High transparent low emissivity silver coating based study has been done specifically to optimize the application in PVT collectors as shown in Fig. 1. It was found that the newly established coating