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Performance of PVT solar collector with compound parabolic concentrator and phase change materials

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ABSTRACT

In this study we examine the solar radiation conversion into thermal energy and energy storage into phase change material (PCM) in the photovoltaic thermal (PVT) collector system. In order to get better solar radiation satisfactory compound parabolic concentrator (CPC) has been mounted on PVT collector. In this study outdoor experiments were carried out to compare performance study between clear day and semi-cloudy day in winter season. PVT solar collector with CPC that act as a solar collector, a PCM tank and CPC was integrated into one piece because of simplicity structure for PCM storage in same unit. No connection pipe *i,e* small area needed for installation and continuous tracking was not needed for better concentration ratio. Total heat loss, total useful energy, thermal efficiency and overall efficiency of the collector by varying different parameters were evaluated using modified equations derived for the energy storage system from the basic derivation of Hottel–Bliss–Whillier. The results show that thermal efficiency of solar collector varies from 40% to 50% for clear day and around 40% for semi-cloudy day. The overall efficiency of the PVT collector between 55% and 63% for clear-day and around 46–55% for semi-cloudy day whereas corresponding top loss value around 3 W/m^2 K for clear day and around 2.5 W/m^2 K for semi-cloudy day. Up to around 3 m from entrance, the plate temperature was increased and then it became nearly steady. But in case of applying same system without PCM temperature was increased sharply.

1. Introduction

Solar energy could be one of primary source of renewable energy that has environmental advantages compared with conventional energy sources. Its main advantage it is ecologically clean and does not produce any waste products or polluting air which provides human activity for sustainable development [1–7]. Conversion of solar energy systems may be classified into two systems such as thermal energy system and electrical energy system. These two collection systems can be combined to form photovoltaic-thermal systems. For betterment efficiency of electrical conversion of photovoltaic modules which needed heat accumulated in the solar cells system is recovered in the form of low-temperature thermal energy [2]. Some of last few years, air and water depend heat carrying fluids have been studied, for different Photovoltaic-Thermal (PVT) systems which developed, and reported in literature. As an example, a hybrid PVT solar system studied and produced electrical power system and hot water and suitable for the various climatic conditions [3–5]. Stores or supplies heat by a PCM is a material that at its melting/solidification temperature using its high thermal energy storage system with its latent heat [4]. Using various manufacturing techniques PCM have integrated in solar heating systems such as storage water heater containing a PCM-filled layer of capsules to get hot water during semi-cloudy hours [5,6]. Concentrated solar radiation fall on the absorber plate of a solar collector by using various solar concentrators.

Last decades, different PVT systems have been studied, developed, and reported in literature based on air and water as heat carrying fluids. To produce hot water and electrical power system suitable for the climatic conditions of Cyprus, Kalogirou et al. have studied a hybrid PVT solar system [7]. A wall mounted solar PVT collector system and its thermal and electrical behavior was discussed by Ji [8]. They have suggested that an increase of the mass flow rate of the working fluid was beneficial for PVT cooling. To reduce the energy consumption in buildings and to provide electrical and thermal energy for domestic users, utilization of a PVT water heating collector for walls in buildings has many advantages [9].

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Nomenclatures

A_{pv}	area of photovoltaic plate (m^2)
$h_{p\text{-}c}$	convection coefficient pipe and cover (W/m^2 K)
$h_{r,p\text{-}c}$	radiation coefficient (W/m^2K)
h_w	wind convection coefficient (W/m^2 K)
$h_{r,c\text{-}s}$	radiation coefficient cover and sky (W/m^2 K)
H	total solar radiation on collector (W/m^2)
q	energy on photovoltaic (W)
Q	useful energy (W)
R_1	thermal resistance between plate and PCM (m^2k/W)
R_2	thermal resistance of back insulation (m^2k/W)
R_3	thermal resistance back of collector and ambient (m^2k/W)
R_4	thermal resistance between plate and glass cover (m^2k/W)
R_5	thermal resistance between glass and ambient (m^2k/W)
R_6	thermal resistance side of collector and ambient (m^2k/W)
S	net energy absorbed by collector (W/m^2).
T_a	ambient temperature (k).
T_c	temperature of glass cover (k)
T_p	plate surface temperature (k)
T_b	temperature of bottom of collector (k)
U_t	top heat loss coefficient (W/m^2 K)
X	insulation thickness (m)

Greek Symbol

η_0	optical efficiency

Different types of solar concentrators are used in last few years but use in this study a compound parabolic concentrator (CPC). Both direct and reflected solar radiation falls on the CPC were used to heat up the system of solar collector [10,11]. With regard to different parameter such as collector length, speed of wind, air mass flow rate in which thermal behavior of the solar air heater was analyzed [12–18]. Photovoltaic-thermal collector system is suitable for better utilization of space, savings when supporting construction and conversion together with electrical and thermal energy. It may be used electrical energy generation and hot water for private house, industrial processing work.

Due to the large temperature differences high power output and high efficiencies results from high-temperature energy sources [19]. Use of CPC helps solar radiation to concentrate onto the absorber plate of a thermoelectric collector. Tchinda et al. [11] have investigated theoretically a solar air heater with a CPC. By using various manufacturing techniques PCM was integrated in solar heating systems. Storage water heater containing a layer of PCM-filled capsules is one the techniques used to get hot water during off-sunshine hours [20]. Double rectangular enclosure with the top enclosure filled with paraffin wax was also used as a system in previous study [21–23].

The aim of this work is to characterize and analyze the thermal performance of a PVT solar collector by using CPC and phase change materials. Furthermore, the overall efficiency of the PVT collector was examined.

2. Experimental work and procedure

2.1. Materials

Corkwood was used to insulate for maximize heat retention and thermocouples for temperature measured. 2.54 cm diameter copper pipe and 0.6 mm plate was used to construct the collector with center to center distance 7.55 cm. PCM was filled into collector from its lateral side through perfect inlet allowing the PCM to be in contract with absorber plate. Solar collector tilted at angle of 35° to the south-directed collector was mounted at the roof top of the Metrology lab. Reflector wall was parabolic in shape and surface of the wall was made of glass as shown in Fig. 1.

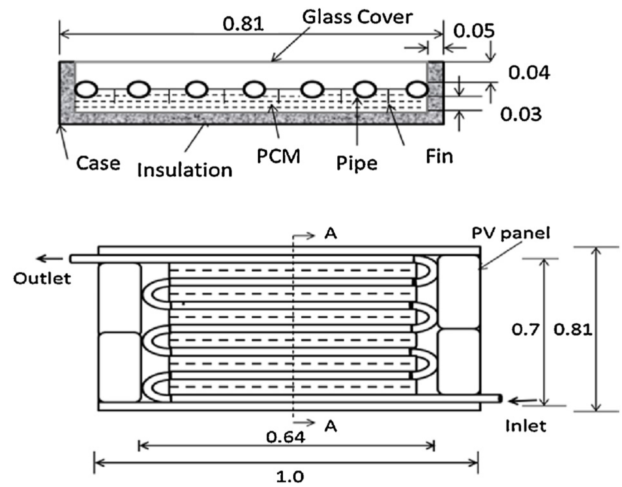

Fig. 1. Sectional view (top) and top view (bottom) of the PVT solar collector system with various dimensions (dimensions in m) used in this study.

2.2. Description of the PVT design

The collector was made with a back layer of paraffin PCM to act as a thermal storage media. With a thin layer of PCM under the absorber plate, during sunshine hours some heat will be stored within the PCM. Melting point of used PCM was 56 °C & Latent heat of fusion is 256 kJ/kg. The temperature of the inlet outlet water, the temperature of the absorber plate is measured by thermocouples. The water flow rate through the test 0.2 kg/s from a constant level water tank. The water source and the inlet to the collector to maintain the flow rate of water to the system by a ball valve. The solar collector with CPC consists of a single glass cover, a concentrating reflector and an absorber plate. In this case of CPC, the angle θc based on the position of the sun corresponding to the earth rotation. For a CPC having tilted from the horizontal and its axis in north-south direction such that the plane of the sun's position is normal to the absorber plate, the acceptance angle is depend on sunshine collection required for a range of time. The maximum concentration ratio was 1.82 with a reflector distance 1.66 m and height of the CPC of 1.89 m as shown in Fig. 2. Directed and reflected incident solar radiation fall on the CPC to heat up the collector system. This location was considered perfect for the geographical location of Rajshahi, Bangladesh. Experimentation started at 11 am and ended at 4 pm and was performed during Dec-Feb'2014.

2.3. Mathematical analysis

Performance of the system is evaluated by calculating the various performance factor of the collector, which include; Top loss coefficient, Total useful energy, Useful energy of water, thermal Efficiency, photovoltaic Efficiency, temperature variation of wax, plate and PCM. Apply implement above this measurement for a solar collector system which use the basic equation of Hottel–Bliss–Whillier with some modification. It was possible to improvement of overall loss coefficient for a solar collector to modify by the mathematical equation. In this study thermal network for single glass cover system Fig. 3. At some typical location on the solar collector plate