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Study of Hybrid Photovoltaic Thermal (PV/T) Solar System with Modification of Thin Metallic Sheet in the Air Channel.

Md. Sadman Sakib Mojumder[1*] Md. Mosleh Uddin[12] Iftakharul Alam[1] HM Khairul Enam[1]

1. Mechanical and Chemical Engineering Department, Islamic University of Technology, Gazipur, Dhaka
2. Technical University of Munich, Germany.

*E-mail of the corresponding author: ms_sakib@yahoo.com

Abstract

The increase of the temperature of PV module gradually decreases the electricity production. To eliminate this problem thermal collector is incorporated with the PV module to allow PV cooling. It has been found that PV cooling increases the electricity production and allows the extra heat to be absorbed by the coolant extracting thermal output. This system is called hybrid PV/T system where water and air can be used as the heat extraction medium. Use of Thin Flat Metallic Sheet (TFMS) in the air channel in PV/T system increase the temperature of the air considerably which has found in several experiments. The comparative performance of PV/T system using four types of shape for thin metallic sheet including flat sheet was investigated. The performance was investigated at Islamic University of Technology in Bangladesh by using an experimental hybrid PV/T system at outdoor .The experiment shows that efficiency of the PV/T system varies significantly with the variation of the shape of the metallic sheet in the air channel. The used shape was flat, saw tooth backward, saw tooth forward and trapezoidal. By the experimental results it is found that the efficiency of the flat metallic sheet is the lowest among the four. Saw tooth backward and saw tooth forward shows the same efficiency and trapezoidal metallic sheet is lower than that.

1.Introduction

The stipulation of energy in our advanced sophisticated life is beyond description. No doubt that, it plays a vital role in the development of any country of this planet as increasing fossil fuel price, energy security and climate change leave an obligatory impact on almost every aspects of human life. Especially when the rising price of fossil fuel has given birth to an excruciating pressure in the economic sector which predisposed the increase in interest rates and investments, the researchers have come forward with a tremendous solution that is to initiate an endorsement or alternate source of energy. Among lots other ideas relating to renewable energy technologies, solar energy is the promising one which is distinguished as Photovoltaic technology in common people [13]. In producing electrical power, it is a known fact that, the efficiency conversion of solar energy to electrical energy using photovoltaic cells is limited by several factors. . Firstly conversion efficiency declines as the temperature of the photovoltaic cells rise. Secondly, the photovoltaic cells are only responsive to a portion of solar spectrum, which is equivalent or higher than the band gaps of the solar radiation. This is one of the reason that make the usage of photovoltaic in tropical countries is less choice. Photovoltaic/thermal (PV/T) systems refer to the integration of photovoltaic and solar thermal technologies into one single system; in that both useful heat energy and electricity are produced [1] .In the case of heating, photovoltaic module is combined with solar thermal absorber collector to produce a hybrid system.

At first the concept of hybrid pvt was proposed and investigated by Kern and Rusell (1978) with the use of water or air as heat removal fluid [2]. Hendrie (1979) developed a theoretical model with conventional thermal collector techniques [3] .Hottel-Whillier model was extended by Florschuetz [4] (1979).A computer simulation work was performed by Cox [12] and Raghuraman (1981) [5] for air type hybrid system. Al- Baali (1986) proposed the use of concentrators [11] .Bhargava er al.(1991)[6] and Prakash (1994)[7] investigated the result of effect of air mass flow rate ,air channel depth,lenght and absorber plate area covered by solar cells on single pass, Sopian et al. on double pass, 1995 and on single pass and double pass hybrid PV/T system performance,1196 (Sopian er al,1995,1996)[8] suitable for solar drying application .Takashima et al.(1994) presented a PV/T system including PV panel placed on solar thermal collector, with a gap between them to achieve and effective PV cooling [9]. Hauser and Rogash (2000)[10] developed a PV/T system based on latent heat storage, installed on building facade which provides warm water. The first air hybrid collector was employed by the University of Delaware[13]. The hybrid collector which was integrated by Böer et al integrate the solar collector to building roof, known as "Solar One" house [14] Tripanagnostopoulos et al used water and air to test the performance of PV/T systems with covered and uncovered collector[15].They used booster diffuse reflector in their system. Based on energy analysis it is found that coverless PV/T collector produces highest available total(electrical +thermal) energy **[17]**. Tripanagnostopoulos modified hybrid PV/T system and introduced a thin flat metallic sheet in the air channel to increase the heating of air and the side of that sheet faced to the PV module was painted black to increase the emissivity.[16]

In our investigation we studied the comparative performance of hybrid pv/t system developed by Tripanagnostopoulos with modification of the thin metallic sheet. We used three shapes of TMS such as saw tooth backward, saw tooth forward and trapezoidal. Thin flat metallic sheet was considered as the standard.

2. Concept of Hybrid PV/T

In general, the main idea of using Photovoltaic/thermal device is to use the solar energy in producing electricity by converting it into heat continuously. Moreover, greatly when it is summer, if the PV mounting is done directly on the building pretense or inclined crown, it avoids unwanted building heating. There are enormous types of Photovoltaic panels. Among them amorphous silicon (a-Si), polycrystalline silicon (pc-Si) or crystalline silicon (c-Si) are the most used and accessible PV modules for building integration as they demonstrate efficiencies in the range of 5% to 14% respectively [19]. Generally their performance gets amplified with the increase of temperature, but when we go for higher temperature operation it declines. As a result when we are opting for greater temperature, the production of electricity certainly decreases at a considerable amount which is an undesirable outcome. So, if we want to get the desirable amount of electricity production, we must extract some heat which can be used for another purpose and keep the PV module heat extraction unit at a reasonable competence level.

There are mainly two types of Hybrid PV/T systems.

2.1 PV/T water

In these systems, water is brought into play as heat reassigning fluid. The PV cells are arranged either directly on the absorber or core on a cover plate with a dielectric material. It depicts that, the only contact between the PV cells and the absorber or the plaster plate is an elevated thermal contact. The heat transmitting fluid runs through the heart of the channels on the absorber and accumulates heat from that. If the cells are glued to the absorber, heat is also extorted from the PV cells resulting in a privileged electrical efficiency of the PV cells. Water type PV/T collectors are discerned according to the water flow prototype. These are differentiated to sheet and tube, channel, free flow and two-absorber type as shown in the figures below:

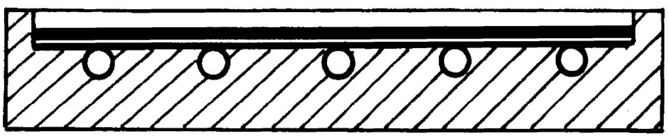

Figure 1: PV/T water system

2.2 PV/T air

The other type of PV/T collector is an air-based system. In place of water, air is used as heat relocating fluid. The PV cells are either attached to the interior of the swathe plate or to an absorber. The air can be ventilated by either natural circulation or forced circulation. Air type of PV/T collectors are discriminated in relation to the flow pattern of air additionally. These are differentiated concerning the flow of air beyond the absorber, beneath the absorber, on both sides of the absorber in single and in double pass. The water type PV/T arrangements can be effectively used in throughout the year. Moreover, this system is more costly than air type systems. Alternatively, the outside air temperature during the day is above 20°C for almost half a year, restraining therefore the application of air type PVT systems in terms of effective electricity manufacturing to a diminutive period [18]. The PVT/WATER systems can also supply to the electrical expenditure of buildings. So, the PVT/Water systems are clearly a better option than the PVT/Air systems from all perspective.

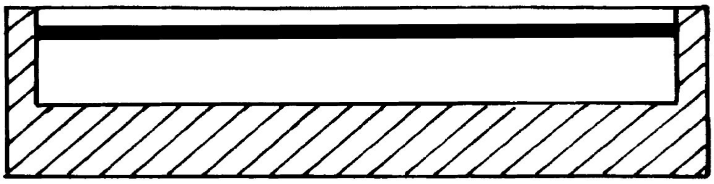

Figure 2: PV/T Air system

3. General Discussion

The PVT system can effectively operate at locations in low altitudes where favorable weather condition exists or marginally in medium latitude to avoid freezing. This system needs special arrangement for air and water circulation through the real surface of the PV panel. This is made by combining the air and water heat extraction method together. The concepts of designing such an arrangement are given here:

Water circulation and the heat extraction can be done by flowing water through pipes in contact with the flat sheet placed in thermal contact with the PV module rear surface.

For air circulation an air channel is usually mounted at the back of the PV modules. Air of lower temperature than that of the PV modules, usually ambient air is circulating in the channel and thus both PV cooling and thermal energy collection can be achieved.

The usual heat extraction mode is the direct air heating from PV module rear surface by natural or forced convection and the thermal efficiency depends on channel depth. The heat extraction by natural airflow depends on the temperature difference between the inserting air in the channel and the PV module. The operation of PV system with high rate of forced airflow gives satisfactory results regarding heat extraction. In natural airflow the flow rate is not usually as higher as in the forced air flow application. The smaller channel depth with high flow rate increase heat extraction, but increase also pressure drop, which reduces the system net electrical output in case of forced air flow, because of the increased power of the fan. In applications with natural convection, the smaller channel depth decrease air flow and these results to an increase of PV module temperature. In these systems large depth of air channel of minimum 0.1 m is necessary along with natural convection. Considering these factors, in this project Natural Convection is applied instead of forced convection to increase the system net electrical output and thereby the overall system efficiency. The heat extraction can be increased using larger heat exchanging surface area in the air channel to promote the convection heat transfer to the circulating air. In order to increase radiation heat transfer, the PV rear surface as well as the opposite channel wall surface should be of high emissivity to transform the infrared radiation to convection heat transfer mechanisms and to heat efficiently the circulating air.

4. Modification

Four experimental setups were fabricated with similar design and dimensions except the shape of the ribs. All works were done in the mechanical workshop of IUT. The whole setup is constructed in a wooden box. PV panels are set at the top of the box. TMS is placed at the middle part of the box on top of which pipes are set for water circulation. Air channel of 0.1 m height is kept under the water heat exchanger. Different ribbed plates (Trapezoidal, Saw tooth (forward), Saw tooth (backward) and flat) of same height and dimensions are placed on opposite wall of the air channel. The whole inner portion of the box is insulated.

Painted black Ribs were placed at the bottom surface of the air channel to increase the heat transmittance by radiation from the TMS back surface to air channel wall and overcome the lower heat transfer from wall to circulating air. This modification is done following the performance improvement of PV/T system showed by Y. Tripanagnostopoulos [17]. The designs of the TMS are shown in the figure 3a-3d.

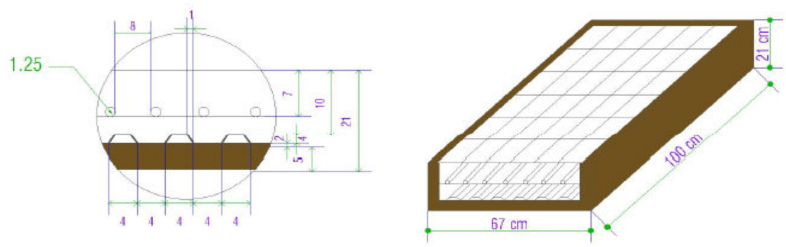

Figure:3a. the setup with Trapezoidal ribbed plate

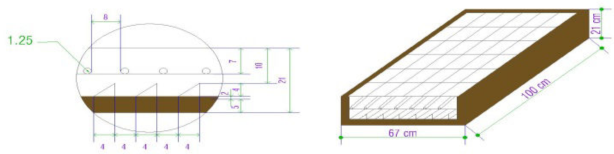

Figure:3b the setup with saw tooth backward ribbed plate

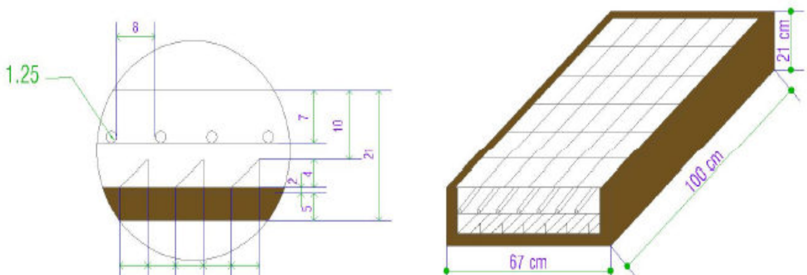

Figure:3c the setup with saw tooth forward ribbed plate

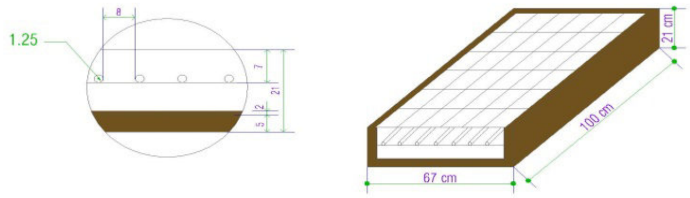

Figure:3d. the setup with flat ribbed plate

Fig shows the schematic diagram of the four experimental setups with different ribbs

5. Experiment Setup

For this project Polycrystalline-Silicon (pc-Si) PV panels are used. It has a rating of 50 watts and 0.45m^{2}aperture area. Its approximate dimensions are (839 × 537 × 50)mm

The selection of the pc-Si PV panel is based on the justification discussed in the Design Concept portion. To facilitate the experiment the suitable and available PV panel has got the above mentioned dimensions and aperture area.

For circulating water copper tubes were used in the project. For the high rate of heat transfer and sufficient rate of water flow in the water heat exchanger the optimum diameter of the copper tube was taken as$^1/_2$"diameter.For the header of the copper tubes a copper pipe of 1 $^1/_2$" diameter was used. The diameter of the header was found by calculating the cross-section area of the copper tubes corresponding to header cross-section area to maintain a uniform flow rate through all the tubes. For the TMS and RIB GI sheet of 22 gauges is used. The GI sheets are painted black to increase the heat absorbency, which will improve the heat transfer with air and water. The shape of the RIBs were varied in the four setups to observe the variation in the heat transfer rates and thereby the performances of the setups. The shapes of the ribs were Trapezoidal, Forward saw tooth, and backward saw tooth and Flat Plate in the four setups.

As insulation Glass Wool was selected. The glass wool was applied at the inner surface of the wooden box carrying the PV panel and outside of the water storage tank to avoid any kind of heat transfer to and from the setup which may decrease the efficiency of the PVT system. The whole setup was constructed in a wooden box with a dimension suitable to the dimension of PV panel. Here Gamari wood is used for better longevity of the setup. A section in the lower part of the wooden box is cut in a rectangular shape in order to make air channel under the PV panel.

30 liters water drum was used for each setup. The drums were kept in a suitable height so that the natural convection of water flow in the experimental setup could be maintained. To keep the PV panels and the water storage tanks in a stable position steel frame and stand is made. The height of the stand was selected in such a way that natural convection of water could be maintained from the water storage tank and the frame for the PV

panel was just a little bit tilted so that natural convection of air flow can be obtained and to get the maximum solar radiation as well. Nylon tube was used between the water heat exchanger and the water storage tank .The dimension of the nylon tube is 1.25 inch.

In order to get accurate temperature reading thermocouple is used. Thermocouples are connected at different positions in the experimental setup. A selector switch is used in each setup and it is connected with the thermocouple to get the thermocouple temperature reading in a digital thermometer. The Incoming Solar radiation was measured by Kipp and Zonen pyranometer.

Figure 4: Heat Exchanger

Figure 5: Photovoltaic Thermal Solar System Set-up

6. Experimental Study

6.1 Equations

Determining the mass flow rate of fluid m=dm/dt (0.02 kgs^{-1}), the fluid temperature rise ($\Delta T_w = T_0 - T_i$) and the specific heat of fluid C_p (4180 J kg^{-1} k^{-1} for water, 1007 J kg^{-1} k^{-1} for air),Heat energy absorbed in one hour for the projected area can be calculated by following relation-

$$Q_{ab} = mC_p\Delta T_w$$

The incoming solar radiation intensity (G in W-m^2) was calculated by bringing the Kipp and Zonen pyranometer into play. The device was incorporated parallel to the PV module plane. Another important parameters, that are outside temperature (T^0 in ^{0}C) and the general temperature (T_i in ^{0}C) at various points of the systems such as, at inlet, outlet, water heat exchanger sheet, air in the duct etc. have been manipulated by using thermocouples. The area at the orifice of the pc-Si PV module has been measured A_a=0.45 m^2 and of a Si PV A_a=0.27 m^2. A 2×10^{-3} m layer of glass sheet has been associated with the supplementary glazing system to evade as much as possible the proliferation of optical losses by the surplus absorption of solar radiation. So solar radiation received in one hour for the projected area –

$$I = G \times A_a \times 3600\ (joule)$$

6.2 Thermal efficiency (η_{th})

As the thermal efficiency is the ratio of heat energy absorbed and solar radiation received per unit time, we can show the relation as written below-

$$\eta_{th} = Q_{ab}/I = (m\ C_p\ \Delta T_w)/(G \times A_a \times 3600)$$

6.3 Electrical efficiency ($\eta_{electrical}$)-

Fulfilling the objective of producing electricity by running the device, we calculated the amount of the current generated (I_0) and the voltage which is the reason for manufacturing the needed electricity. This voltage is called the closed circuit voltage (V). Now we can determine the value of electrical efficiency through the following equation-

$$\eta_{electrical} = (V \times I_o)/I$$

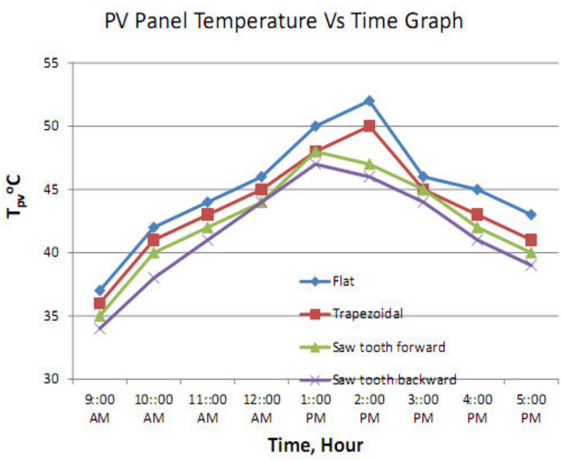

Fig 6a: PV panel Temperature Vs Time graph

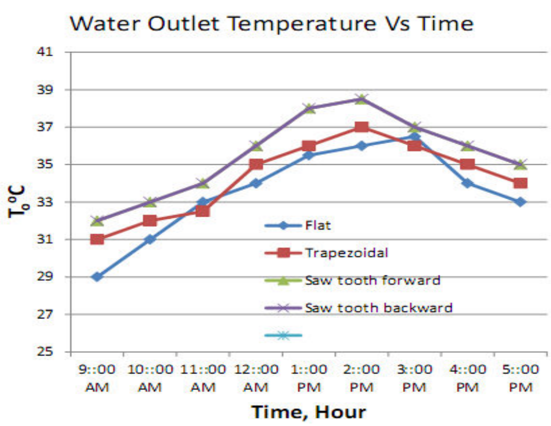

Fig 6b: Water Outlet Temperature Vs Time

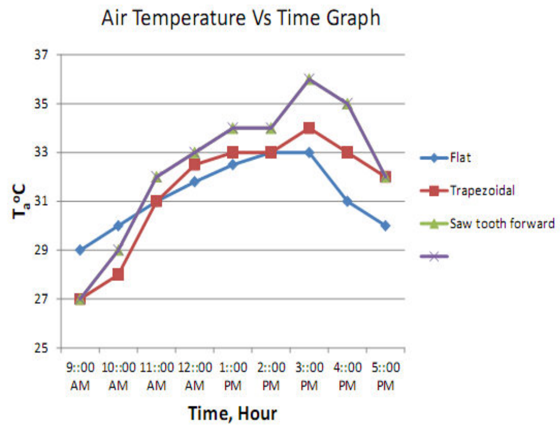

Fig 6c: Air Temperature Vs Time Graph

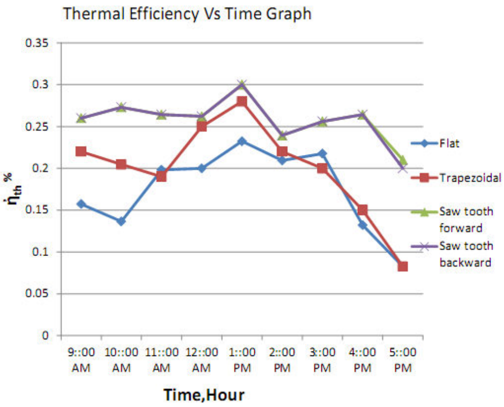

Fig 6d: Thermal Efficiency Vs Time Graph

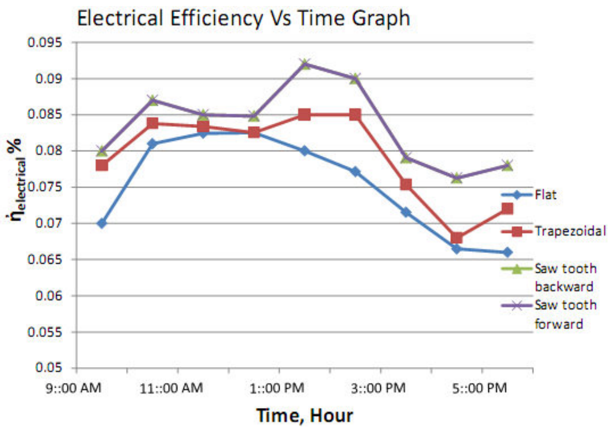

Fig 6e: Electrical Efficiency Vs Time Graph

The experimental result in Fig 6a shows the fluctuation of the PV panel with time. The figure shows similar patterned temperature rises with slight difference between the four setups. PV panel temperature rises from 9 AM to 1.30 PM at noon and then decreases rapidly. In a moderate sunny day of September the maximum temperature of PV panel was found 51°C for flat plate rib, 49°C for trapezoidal rib and 48°C for saw tooth backward and forward rib. So for saw tooth backward and forward the cooling of PV module is high. For flat plate cooling is low. The trapezoidal rib shows the medium cooling of PV module.

Fig 6b shows the temperature of water outlet for different setups with time. The temperature of water outlet increases with time in similar pattern from 9am to 3 pm then deceases with time. In a moderate sunny day of September 2011 the maximum water outlet temperature was found for saw tooth backward and forward 38.5°C , for trapezoidal it was 37°C and for flat plate it was 36°C.

Saw tooth backward and forward rib both gives the same temperature rise of water which was maximum and the flat rib gives the minimum rise of water outlet temperature. For trapezoidal rib it was in the middle.

Fig 6c represents the temperature of the air channel (T_{air}) of different setups with time. The figure shows the pattern of temperature rise in the air channel. From 9 am to 2pm the temperature rises and after 2pm it decreases with time. In a moderate sunny day of September 2011 for saw tooth backward and forward the air temperature raised to maximum 36°C, for trapezoidal 34°C and for flat plate 33°C.

So the air temperature raises more in saw tooth backward and forward rib and for flat rib it is low. For trapezoidal it is in between them.

Thermal efficiency for all setups with time is shown in fig 6d. It was found that thermal efficiency was increased rapidly for all the setups. But with the time it decreased. For the recirculation of same water through the pipes and reservoirs the temperature difference between the inlet and outlet decreased with time. For saw tooth backward and forward rib the thermal efficiency was found maximum 30 %, for trapezoidal rib 28% and for flat rib 23%.

So for saw tooth backward and forward shows the highest efficiency among the four ribs. The electrical efficiency with time for all four setups is shown in fig 6e. We have measured the electrical efficiency of the PV panel with load. A 20 Watt bulb was set with each setup. The voltage and current was measured with multi meter. It was found that as the temperature of the PV panel decreases more in saw tooth backward and forward rib, the electrical efficiency increases more. For saw tooth backward and forward rib the maximum electrical efficiency was 9.2%. For trapezoidal rib it was found 8.5%. For flat rib it was found 8.4%

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