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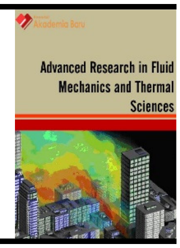

Advances in High Efficiency Photovoltaic Thermal Solar Collectors

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Kamaruzzaman Sopian[1,*], Ali H A Alwaeli[1], Husam Abdulrasool Hasan[1], Ali Najah Al-Shamani[1]

[1] Solar Energy Research Institute (SERI), Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor Darul Ehsan, Malaysia

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ABSTRACT

Two solar energy collection systems commonly used are the flat plate collectors and photovoltaic cells. Normally, these two collection systems are used separately. These two systems can be combined together into one compact unit known as photovoltaic thermal (PVT) collectors or sometimes known as hybrid collectors. These special design solar collectors can simultaneously generate both electricity and thermal energy. There are varieties of terrestrial applications for PVT such as building facade integration, window integration, fence / barrier integration, parking lot integration, and etc. The recent applications and advances on high efficiency and cost-effective PVT collectors will be presented. These include the use of advanced heat transfer features such as jet impingement, bifacial solar cells, extended surfaces, optical enhancement and the use of nano fluids. Finally, the way forward for R&D in PVT technology.

1. Introduction

The utilization of the solar radiation spectrum to produce energy is considered one of the famous renewable energy methods due to its relative simplicity when implemented by ordinary people and availability; the sun shines everywhere. The two major types of energy that solar produces are electrical and thermal. Electrical energy generation is the function of the solar cell or as it is known the Photovoltaic (PV), while thermal generation is done using a solar thermal collector [1-2]. However, since the Seventies a more comprehensive method to utilizing more of the solar spectrum was introduced which is called Photovoltaic Thermal (PV/T). PV/T combines the Photovoltaic panel (PV) and Solar Thermal collector. Solar thermal collectors have higher efficiencies in comparison to separate PV and solar thermal units [3].

This is since temperature is subtracted from the PV panel and injected into the thermal collector. Hence, temperature of PV cell effects its Open Circuit Voltage (V_{OC}) negatively [4]. Reducing the temperature of the PV panel will help maintaining the V_{OC} while using this temperature to increase

[*] *Corresponding author.*
E-mail address: ksopian@eng.ukm.my (Kamaruzzaman Sopian)

thermal output of thermal collectors which in turns will raise the overall efficiency. The main factor in having more thermal conductivity is the working fluid within the solar thermal absorber. Different fluids (air, water, nanofluid etc.) can be used to enhance the PV/T system, also, attaching the absorber to the back of the panel will ensure successful heat transfer [5]. Various methods have been inducted to the field to enhancing the overall efficiency of PV/T. This paper will discuss some of those methods that represents a mile stone in the development of this technology.

2. Air Based PVT

Air based Photovoltaic thermal systems use simpler structure than water-based PVT systems. This will affect the overall cost of the entity which dictates the user's choice; low construction and operation costs will encourage investment in PVT/Air collectors. Air as working fluid is the most common method for PV/T, even though air has less thermal conductivity than liquids. The air is circulated through the system either through natural convection or forced convection. The structure is composed of a hollow metal structure on the back of a PV plate connected to an enclosed space to aid in air circulation process [6-7]. This technology can be classified into single pass and double pass. Other classifications are glass covered, uncovered, wall mounted, roof mounted etc. Single pass requires lesser area, while double pass has better performance [8]. Figure 1 shows the two types. Srinivas and Javaraj [9] performed an investigation of PV/T double pass air heater. Authors found that fluctuations are in effect outdoors due to continuously changing ambient temperature and solar insolation. Continuous fluctuations may cause expansion and contraction to the layers of the PV panel which may lead to thermal stress. Thermal stress will reduce the expected lifetime of the panels.

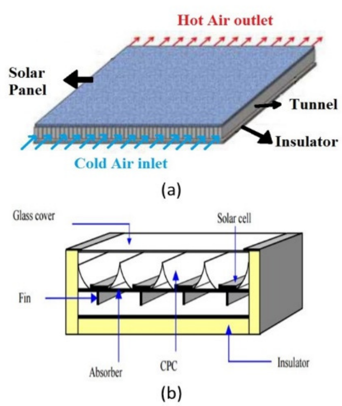

Fig. 1. (a) single pass PV/T (b) double pass PV/T

However, this could be solved by operating at higher mass flow rate [9]. Farshchimonfared *et al.*, [10] performed theoretical and experimental study to an uncovered, roof mounted, single pass PV/T air collector which is connected to an air distribution system and employed for space heating application in typical residential building. The study correlates between constant temperature rise and channel depth, air mass flow rate and air distribution duct diameter in order to optimize these values. The study presented the following results: The optimum value of mass flow rate per collector area is around 0.021 kg/s m^2, the optimum air distribution duct ranges between 0.3 and 0.5 m and the optimum depth (D_{opt}) value ranges between 0.09 and 0.026 m. An increase in collector length to width ratio and collector area will cause an increase in optimum depth [10]. Air based PV/T have massive potential due to it being common and relatively cheap which makes it on constantly on demand. This will open the door for more comprehensive techniques to improving its overall efficiency as seen in the literature [11].

3. PVT with Nano Fluids

3.1 Enhancement of PV/T with Nanofluid

Nanomaterial are particles of a material ranging in size between 1 and 100 nanometers. Improving the heat transfer properties of PV/T by mixing nanomaterial with a conventional fluid is the premise of this technology. The point of using nanofluids is because of their thermo-physical properties which are suitable to heat exchanging applications [12]. Different types of nanoparticles have been studied throughout the literature and experimented on such as Silicon carbide (SiC), aluminum oxide (Al_2O_3), Zinc oxide (ZnO) etc. Figure 2 shows an image of a SiC nanoparticle taking by a Field Emission Scanning Electron Microscope of a Silicon Carbide (SiC) nanoparticles. This shows the depth of material analysis involved in the process of using nanofluids; where stability of, and material characteristics are studied during the selection process of the particles.

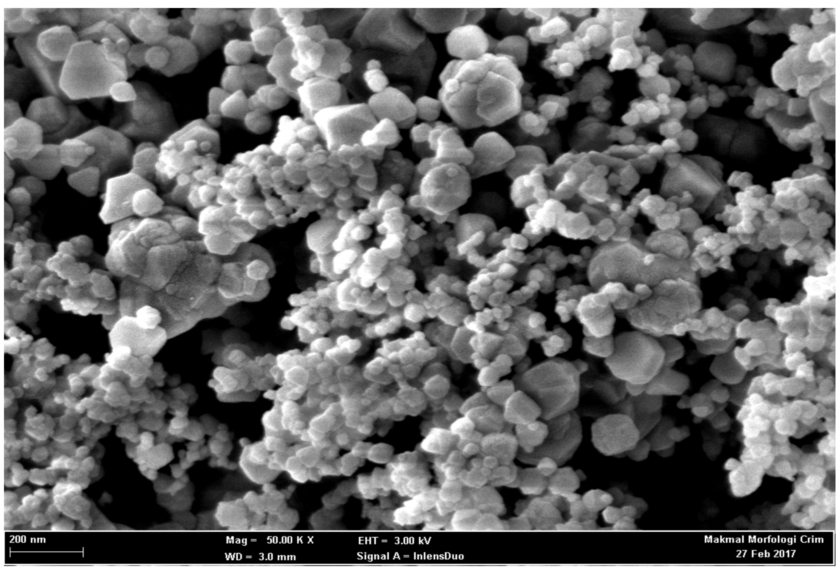

Fig. 2. Typical FESEM of a nanoparticle

Li *et al.*, [13] studied the effects of three different nanofluids on tubular solar collector's performance. The nanofluids are Al_2O_3-H2O, ZnO-H_2O, and MgO-H_2O. The results obtained from this study show 0.2% volume concentration of ZnO–H2O nanofluid is the best base-fluid for the collector. The element of experimentation and comparisons is very important to finding the best solution in this field. He *et al.*, [14] investigated the characteristic of light-heat conversion for two different nanofluids: TiO_2-H_2O and water–carbon nanotube (CNT). The investigation took place in a vacuum tube solar collector during cloudy and sunny weather conditions. The results obtained show that a weight concentration of 0.5% CNT-H_2O exhibits good light heat conversion characteristic. CNT–H_2O nanofluid relative to the TiO_2–H_2O nanofluid exhibits higher temperature. Which ultimately makes it more suitable for use in vacuum tube solar collector.

3.2 Grid Connected PV/T with Nanofluid

More aspects of the overall PV/T system could be enhanced and the use of PV/T with nanofluid maybe most suitable for Grid-connected purposes. The utility grid may suffer occasional instability and/or power outage due to the high demand in rush hour times. PV/T system with nanofluid is a reliable technique to injecting the grid and if utilized by a good number of users hooked into the gird it could be a different maker. This will also benefit the user financially if suitable laws are in place such as the Feed-in-Tariff. Figure 3 shows a block diagram of a typical PV/T with nanofluid linked to the utility grid. From Figure 3 the following components to the system are: Heat exchanger, hot water container, nanofluid tank, Photovoltaic panel, thermal absorber and pumps. The system in the figure is installed in the Green Energy Technology and Innovation Park in the national university of Malaysia.

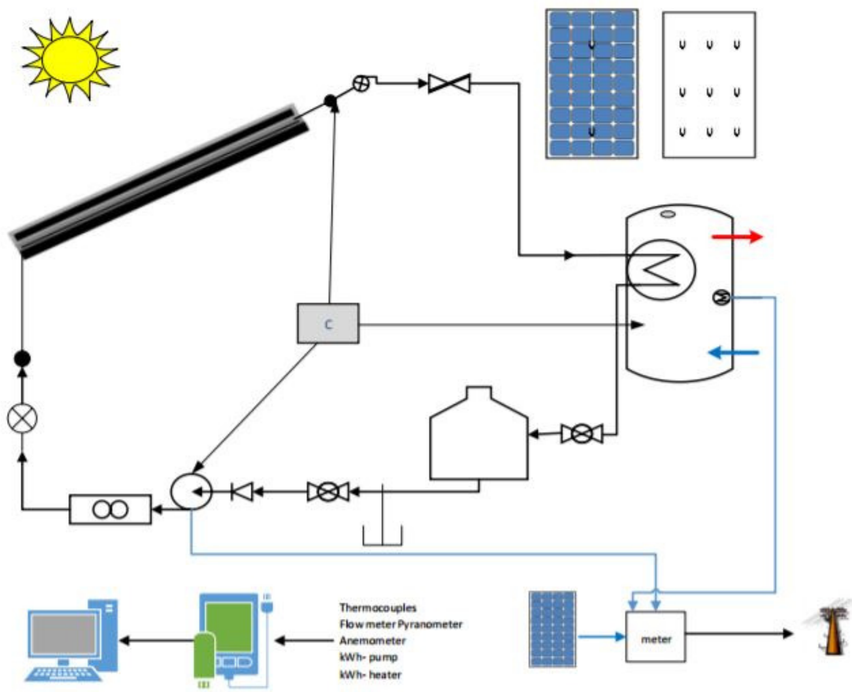

Fig. 3. Grid-Connected PV/T system with nanofluids

Figure 4 shows the energy yield for grid connected PVT system with and without nanofluids. It can be seen that an increase in about 30% of the energy yield using nanofuids has been observed. The system is designed for experimentation purposes therefore; multiple sensors are hooked and linked to a data acquisition system which collects and transfers data to a personal computer. As for the grid-connection two meters are present in the entity, one for input and the other for output. As for the inverter, a suitable inverter was used to convert from DC to AC and synchronize with the grid. A smart inverter is more suitable for such systems. From the literature, a clear lack in techno-economic assessment of gird-connected PV/T systems with nanofluids exist. Certain electrical values like yield factor, capacity factor, performance factor, and energy payback period must be calculated. As for the economic aspect; life cycle costs (LCC) and cost of energy (COE) must also be calculated to give an impression regarding GCPVT with nanofluids as an investment. Furthermore, there are some issues that must be addressed like the synchronization and grid stability. The GCPVT must have good synchronization with the grid otherwise further instability will be achieved.

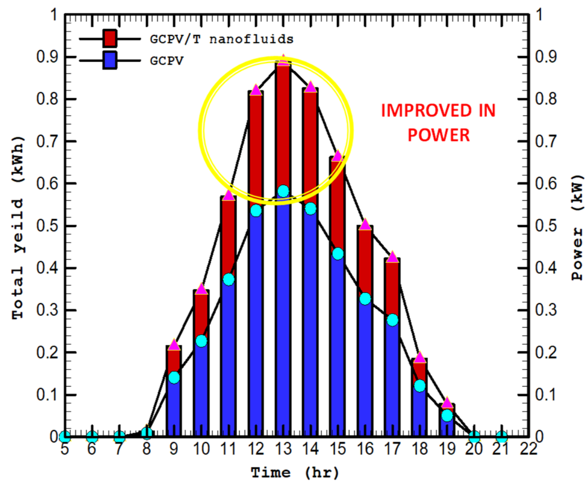

Fig. 4. Grid-Connected PVT system yield with and without nanofluids

4. PVT With Jet Impingement

The use of nozzles to jet a working fluid to the flat-plate PV/T collector to reduce the cell temperature of the panel and improve overall efficiency. The process of optimizing the nozzle arrangement in hybrid jet impingements PV/T systems is very beneficial to improving the cooling rate. Barrau *et al.*, [15] conducted experimental work to analyze effects of hybrid jet impingement/micro channel cooling device on the densely packed concentrated photovoltaic (CPV) receivers. Jet impingement here is employed to maintain nominal operating temperature range for the PV panel. The obtained results show a temperature uniformity and thermal resistance coefficient provided by device that meets the CPV receivers' requirements. Barrau *et al.*, [16] conducted performance analysis of a novel hybrid jet impingement/micro-channel cooling system used at high concentrations for densely packed PV cells. The minimum thermal resistance coefficient of the scheme is around 2.18×105 K m^2 /W. As for the pressure drop, it is lower in the micro-channel devices. The obtained results display superiority of net PV output of PV receiver when cooled by the new design relative to being cooled by the micro-channels.

Figure 5 shows a schematic diagram of an indoors PVT system with set levels of solar irradiances and mass flow rates. The components of this system are mostly like the GCPVT system in Figure 3, with few differences such as four parallel tubes and 36 nozzles with direct fluid injection to the back of the PVT collector. This system is setup at the lab of Solar Energy Research Institute (SERI). Furthermore, this technique presents many challenges as heat transfer through jet impingement is hard to determine, where it depends on various parameters such as Prandtl number, Reynolds number, Jet diameter, wall-to-nozzle spacing and the working fluid. Nanofluids seems to have better performance due to their excellent thermal conductivity, stability, pressure drop and pipe wall abrasion which allows it to avoid penalty of pumping power. Figure 6 shows the increase in power output for PV and PVT with jet impingement for various nanofluids.

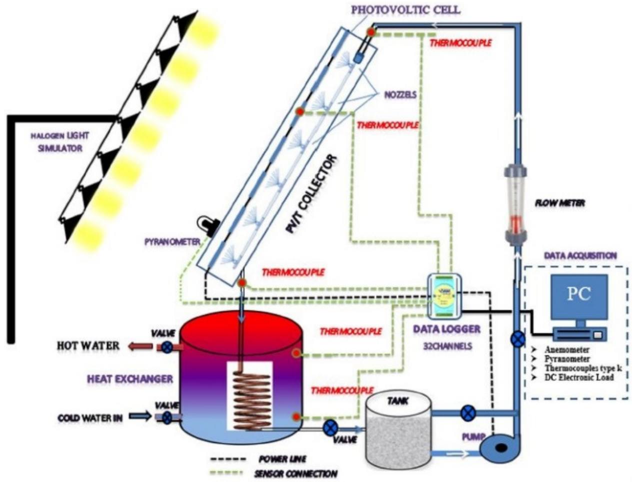

Fig. 5. Schematic diagram of indoors PVT with Jet impingement

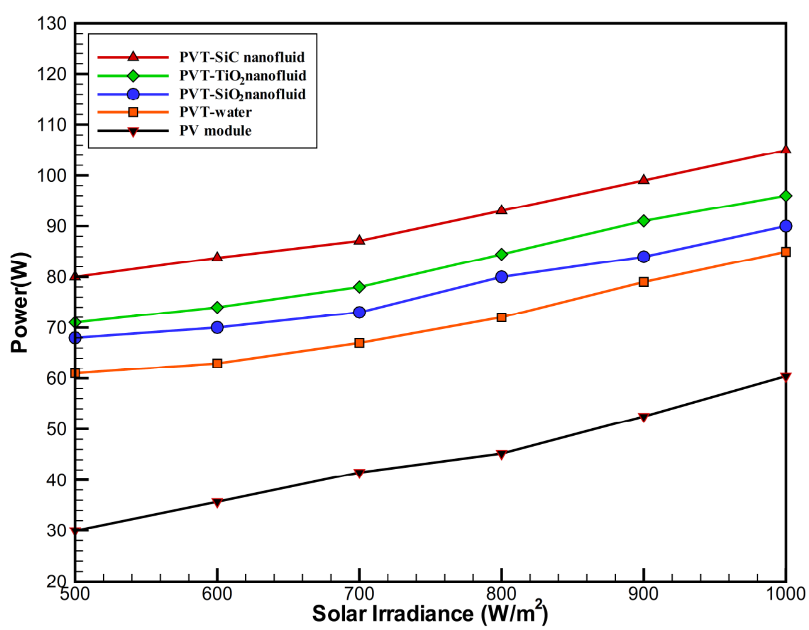

Fig. 6. Power versus the solar irradiance levels on PV and PVT various nanofluids

5. Conclusions

This paper illustrates various cooling techniques and technologies associated to photovoltaics. These techniques are still in the development stage and the need for further research to enhancing the overall output of solar panels (photovoltaic or solar thermal) is very important to making solar energy user friendly and cost effective. Bifacial Air based PV/T seems to exhibits superiority over conventional PVT/Air type. As for nanofluids which is considered a recent development in the PV/T field. It is important to explore the different thermo-physical properties and effects of sizes, concentration and addition of surfactant. Finally, the jet impingement technology which can be used to cooling photovoltaic thermal (PV/T) device. Even though, these technologies have contributed to raising the overall PVT efficiency it is important to note that further research must be made to discovering the effect of such technologies over the long term and assessing their benefits financially to the user.

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