Different Techniques of Solar Rooftop Combo-PV/T System Implementation: Materials and Installations

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Abstract. Sun radiation been utilized to produce clean and environmental-friendly solar energy. Beside has been used as heat energy, it also has been used as electricity. Solar photovoltaic and thermal (PV/T) collector is a combo system that utilize solar PV technology and solar heater technology all together in one simply module. At the time PV system is irradiated with solar energy, the cell temperature increases significantly. As the heat that extracted is passing through a heat extracting fluid in such way under the module, then this heat is transferred become hot air and water. This paper aims to reveal several materials that been used to design solar combo-PV/T collector modules and their gains and drawbacks, and the installation onto households’ rooftops. Water-based and nanofluids-based PV/T modules are two technologies that being considered in this paper. All the comparisons that have been made turned out to match the assumption that the greater the difference of temperature between ambient temperature and temperature of the cells of the module, the less efficient the electrical efficiency and electrical output of the PV module and also to overcome the problem of low thermal conductivity. The considered water-nanofluids PV/T solar collector modules then put into account for better performance to improve the raised problem of thermal conductivity.

1. Introduction
As sun radiation been widely used over several decades to produce clean and environmental-friendly heat and electricity, the performance of solar thermal and solar photovoltaic (PV) as the collector of sun radiation must put into account. People used to install solar thermal and solar PV separately on their rooftop in order to get hot air and hot water and also electricity. However, these solar energy collector’s technologies are less aesthetic, and need more space on the rooftop.

For that reason, the solar PV/T collector technology is developed. This technology is a hybrid sun radiation collector technology that deploy solar PV technology and solar heater technology in one module. When a PV system is irradiated with solar energy, the cell temperature increases significantly. The greater the temperature differentiation between ambient temperature and cell temperature occurred, the less efficient then happened to the electrical efficiency and electrical output of the PV module. In order to increase the electrical efficiency, this excess heat is extracted by passing a heat extracting fluid (air or water) under the module. This is the fundamental of PV/T collectors integrated method [1-3].

Several references have reviewed two PV/T solar collector modules technologies based on water [4-5] and nanofluids [6-7]. In one hand, water-based PV/T mostly utilizes water as coolant in PV/T system, the water flow can be categorized as natural, force and hybrid system flows, respectively [4], yet, this PV/T modules technology has low thermal conductivity problem. On the other hand, the nanofluids PV/T that suspending nanoparticles in water has improved the raised thermal conductivity problem, and consequently, performed a significant positive effect on the heat transfer.
This paper reviewed the differences of those two techniques of PV/T modules which for further study might be used as a consideration to build a better module that performs water-nanofluids as coolants for PV/T collectors.

2. Performance of PV/T solar collector module

As indicated in [8], the combination of PV cells and solar thermal collector into a single module allows the cooling of PV cell and simultaneously utilizing the extracted heat for domestic use. PV/T solar collector module can reduce the operating temperature and improve system efficiency. It also produces thermal energy and electricity simultaneously. The collector module is consisting PV panel, insulation and frame. Physically, PV/T collector consists of one or more glass sheets or a transparent material placed atop an absorbing plate with air flowing around it. One way to increase the collector’s efficiency is by using heat transfer area through finned absorber, corrugated surfaces, and porous media [9-10].

Figure 1 illustrates the fundamental mechanism of solar PV/T collector. Electricity production is provided primary priority in PV/T system applications. For that reason, the module absolutely preferable to keep PV unit operating temperatures maintain the lowest possible in order to get the appropriate efficiency levels.

Figure 1. Fundamental work of solar PV/T collector.

PV/T collector can be classified into four types base on heat transfer medium; air-based PVT collector, water-based PVT collector, the combination of water/air-based PVT collector, and nanofluid-based PVT collector [1].

This section discusses the water- PV/T and nanofluids-based solar collector modules, respectively. The comparison then made to describe the benefits and drawbacks of those two modules due to then improving the modules by combining them into the water-nanofluids PV/T solar collector module. The benefits and drawbacks are gained from the overall energy and exergy efficiency of the considered solar PV/T collector modules.

2.1. Water-based PV/T

The development of water-based PV/T collectors is interesting and very promising area of research since currently this PV/T collector module is also used as water heater. Despite the cost-effective improvements on solar energy conversion, the uptake rate is still lower than the independent PV and thermal systems [4]. Figure 2 indicates the material structure of water-based PV/T collector module. A sandwiched structure of four layers namely photovoltaic cells lamination beneath the cover with a small air gap/tubes or flowing channels through the absorber which closely adhered to the PV cell layer and a thermally insulated layer located right below the flow channels. All the layers are fixed into a framed module using the adequate clamps or various joining methods and connections [11].
Studies on water-based PV/T system mostly focus on determining suitable water flow rate and temperature, sizing of water tubes for optimization and structural configurations including parts, components, connections etc.

![Figure 2. Material structure of water-based PV/T solar collector.](image)

Figure 2. Material structure of water-based PV/T solar collector.

Figure 3 shows the mechanism of water-based PV/T collectors from the cross-sectional perspective point of view. Water-based PV/T collectors has similar structure as the conventional flat plate solar collectors. The absorber consist of tube is attached to the PV panel in order to use for heating purposes. The collector could achieve the enhance cooling effectiveness due to the high thermal mass of the water over the air [8].

In accordance to reference [12], the techniques are used to enhance the performance of water-based solar PV/T collector can be classified in the term of physical parameter and operating condition toward the environment due to seek the thermal efficiency based on six operating factors, namely ambient temperature, irradiance, cell efficiency, wind speed, PV cell covering factor and ratio of mass water to collector area.

![Figure 3. Water-based PV/T fundamental work, cross-sectional perspective point of view.](image)

Figure 3. Water-based PV/T fundamental work, cross-sectional perspective point of view.

Mechanisms of absorbing and transferring the residual heat dissipated as a result of exposure of solar cells to solar radiation is designed in different configurations and dimensions due to optimize the module performance. Solar PV/T collector water-based type is effectively recommended for use in low latitude regions since the mains water supply temperatures are below 20°C in a year and function best in all climates except for instances prone to freezing [11].
The overall energy and exergy efficiency of the water-based solar PV/T collector as stated in [8-12]. For the energy efficiency, it is calculated in such way using equations as the overall efficiency of PV/T. Whereas $\eta_{PV/T}$ is the sum of solar collector thermal efficiency, $\eta_{th}$ and PV’s electrical efficiency, $\eta_{PV}$ used to evaluate the performance of PV/T (1). The thermal efficiency of flat plate water-based solar PV/T collector is a ratio of the useful thermal energy, $Q_u$ to the overall incidence irradiations, $I$ (2). The electrical efficiency of PV modules, $\eta_{PV}$ which is the ratio of measured output power to the overall incident solar radiation (3).

$$
\eta_{PV/T} = \eta_{th} + \eta_{PV}
$$

$$
\eta_{th} = \frac{Q_u}{I}
$$

$$
\eta_{PV} = \frac{P_o}{I_A \varepsilon}
$$

In addition, the exergy efficiency can be defined as the ratio of the thermal efficiency of an actual system compared to an idealized or reversible version of the system for heat [12]. The exergy efficiency can be calculated using exergies for thermal and PV (electrical). By assuming the insignificant effects of potential and kinetic energy changes, then the exergy efficiency of a water-based solar PV/T collector is defined as ratio of net output exergy to net input exergy [8]. It can be calculated as (4).

$$
\eta_{Ex,PV/T} = \frac{E_{x0}}{E_{xi}} = 1 - \frac{E_{x_d}}{E_{xi}}
$$

Some benefits of water-based solar PV/T collector can be found in [12], they were in the term of, i) bifunctionality: the way the module produces electrical energy and heat simultaneously; ii) efficiency: as the combination of energy and exergy efficiency resulting high independency systems; iii) improved thermal comfort: reduces air conditioning load; and iv) the facts that water works better as a working fluid than air, thereby increasing electrical energy harvesting. The water-based solar PV/T collector also has limited drawbacks. Once flat plate collectors are not supposed to be tracked, they have great amount of cosine losses, therefore less total energy falls on a rigid surface during the day. In addition, the maintenance cost for this type of solar collector is not cheap [13].

As for the installation, water-based solar PV/T collector is most suitable for areas with limited space. It is also consistently higher efficiency per unit area and can be easily mounted on existing roofs with minimal modifications. When come to the aesthetics point of view, it is more uniform than side-by-side systems.

2.2. Nanofluids-based PV/T

The use of nanofluids in solar PV/T module is given certain research consideration. Nanofluid material can be used as both for heat transfer medium and as optical filter that isolates the thermal toward PV and thermal receiver. According to [6] and [14], to produce nanofluids, the main aspects to consider are the nanoparticle materials and base liquids, although this process presupposes the close control of a set of important parameters in order to obtain functional thermal fluids. Nanofluids as a working fluid in the solar PV/T collector achieved high temperature in the thermal part of the system. it is also improved the performance of the system (electrical and thermal efficiencies) and reduced the required PV/T system area due to high production system per unit area [6].

Extensive work on the flowing nanofluids through optical filter improved the efficiency of the PV/T system. According to [16], various factors such as the concentration, flowrate, irradiance of the nanofluids, size of the nanoparticle, geometry of microchannel, type of base fluid are affected the
efficiency of nanofluid-based solar PV/T collector. The most common methods to extracting heat from the PV units via nanofluids by employing heat collector at the rear end of the panel and using nanofluid as a liquid in spectral splitting filter joined on the front surface of PV module. Sometimes, both methods are used simultaneously in order to increase the efficiency. Nanofluid used as the cooling media. The overall system efficiency may be improved with minimal changes to the design of the structure by using a working fluid with improved heat transfer properties.

Figure 4 illustrates the diagram of a nanofluids-based solar PV/T collector. In single pipe system, there are two sections of pipe; primary section and secondary section. Primary section is set underneath the rear surface of the PV module having aluminium sheet in between. Primary section further elongates above the upper surface of it. Nanofluid enters from the inlet of primary section, thus, absorbing heat of the module. Heated nanofluid further passes over the PV’s upper surface, in turns filtering the solar radiation. Part of radiation having wavelength equal to silicon bandgap is filtered and rest of the section is absorbed by the nanofluid flowing in the secondary channel which gets out of the secondary pipe at secondary outlet. Air exists between upper surface of PV module and secondary channel section. As the air gets hot, it flows in upward direction and the cool air still remains in contact with PV surface. It is assumed that no convection current is produced in the air.

The overall energy efficiency of the nanofluids-based solar PV/T collector as stated in [15-17]. Energy balance of nanofluids-based solar PV/T collector calculated by using (5), then the overall efficiency of the system is found by (6).

\[
\dot{E}_{\text{in}} = \dot{E}_{\text{el}} + \dot{E}_{\text{th}} + \dot{E}_{\text{loss}}
\]

\[
\eta_{\text{net}} = \frac{\dot{E}_{\text{el}} + \dot{E}_{\text{th}}}{\dot{E}_{\text{in}}} \Rightarrow \eta_{\text{net}} = \eta_{\text{el}} + r \times \eta_{\text{th}}
\]

Some benefits of nanofluids-based solar PV/T collector can be found in [17], a small area of nanofluid-based PV/T system may produce the amount of energy equivalent to a large area of a standard PV-only can produce. The optimized optical and thermal nanofluids-based PV/T hybrid system is a reliable solution to electrify remote off-grid regions at a low cost and to provide a potentially large supply of useful thermal energy. Also stated in [16], by using surfactant in the nanofluid can also surge the performance. The measures that can refine the performance of these systems include: i) glazing can drastically improve the nanofluid-based solar PV/T collector’s performance; ii) simultaneously using
optical filters over the surface and thermal collector at the rear end can also elevate performance; and
iii) applying alternating magnetic field around the flow channel can increase the performance of system
if the Ferro-nanoparticles are being used. The limited of nanofluids-based solar PV/T collector stated in
[16], while using nanofluids include instability, agglomeration, high pumping power, and erosions.
Stability improvement is the most important need of the hour in order to further proceed towards
commercial use of nanofluids, as no perfect method of preparation and processing of stable nanofluid
has been determined up-to-date. However, it is very possible to improve these limitations.

As for the installation, nanofluids-based solar PV/T collector is most suitable for areas with narrow
space. It is also reliably higher efficiency per unit area and can be easily mounted on existing roofs with
minimal modifications. When come to the aesthetics point of view, it is more uniform than side-by-side
systems.

3. Performance of considered water-nanofluids PV/T collector module
The capability of nanofluids when it is combined with water to enhance the performance of solar PV/T
collector has been studied in many different techniques. The effectiveness of utilized water-nanofluids
as absorber fluids in solar PV/T collector strongly depends on the type of nanoparticles and base fluid,
volume fraction of nanoparticles, radiative properties of nanofluids, temperature of the liquid, size and
shape of the nanoparticles, pH values, and stability of the nanofluids [18]. Figure 5 shows the schematic
diagram of water-nanofluids solar PV/T collector.

Figure 5. schematic diagram of water-nanofluids solar PV/T collector.

In reference [7], a combination of water and CuO nanofluids was investigated. The influence of CuO
nanofluid confected the heat transfer coefficients. Since the excellent thermo-physical properties of the
nanofluid comparative to water, then the simultaneous operation, the thermal performance of each fluid
is directly associated with its counterpart. The overall energy and exergy efficiency of the water-
nanofluids solar PV/T collector are expressed in (6) and (7).

\[
\varepsilon_{\text{pu}} = \frac{\dot{E}_{\text{th}} + \dot{E}_{\text{el}}}{\dot{E}_{\text{in}}} = \varepsilon_{\text{th}} + r\varepsilon_{\text{el}}
\]

By using the considered water-nanofluids solar PV/T collector, the electrical and thermal efficiencies
were found higher than those of the water-based and nanofluid-based PV/T systems. We modelled the
eq. (1) – (7) in such way using MATLAB. Figure 6 illustrates the comparison of the parameter namely
electrical and thermal output power, and also electrical and thermal efficiencies of water-based,
nanofluids-based and water-nanofluids based solar PV/T collectors, respectively. The electrical and
thermal outputs of those solar PV/T collectors as the critical parameters are compared showed that the
most reliable solar PV/T collector is water-nanofluids solar PV/T collector.
Figure 6. Comparison of types of solar PV/T collectors in the efficiencies point of view.

Some benefits of water-nanofluids solar PV/T collector can be found in [19], namely: i) wide array of commercial applications due to its coreless capabilities; ii) energy and money conserving out of electricity; iii) excellent thermal insulation in a thin layer system which no influence to the weight; iv) no moisture infiltration, which gives the insulation the benefits of corrosion resistance; v) easy installation and has high efficiency. Thus, It was found that the use of nanofluids and combining it with water in the solar collector field can play a crucial role in increasing the efficiency of this device.

4. Conclusion
As can be seen from the reviews of water-based and nanofluids-based solar PV/T collector, and from modelling the considered water-nanofluids solar PV/T collector in MATLAB, the energy and exergy efficiencies of the collectors meet that recently the most efficient one is water-nanofluids solar PV/T
collector. In addition, a water-nanofluids solar PV/T collector without any extra energy consumption can be a suitable option to improve the cooling in a PV/T system significantly.

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