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# COOLING OF PV NON-CONCENTRATED SYSTEMS USING NANOFLUIDS: A REVIEW

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***Abstract.*** *In the current scenario, in which more and more people are concerned about the degradation of the environment due to the use of polluting energy sources, renewable energies are becoming increasingly important. Among them, the photovoltaic (PV) system has a considerable percentage in energy production. However, as the temperature of the photovoltaic panel increases, its electrical efficiency decreases. Therefore, in an attempt to improve electrical efficiency and increase the useful life of the panels, different cooling methods (active and passive) have been widely studied. Active cooling methods are based on the flow of a working fluid to exchange heat with the surface of the panel. In this sense, nanofluids appear as a working fluid with thermophysical properties that can improve heat transfer processes in this type of application. When active cooling methods are used to remove heat from photovoltaic panels, these systems have the capacity to produce both electrical and thermal energy and they are commonly known as hybrid photovoltaic thermal systems (PV/T). This article reviews and summarizes the main experimental works focus on non-concentrated PV/T systems using nanofluids as working fluids.*

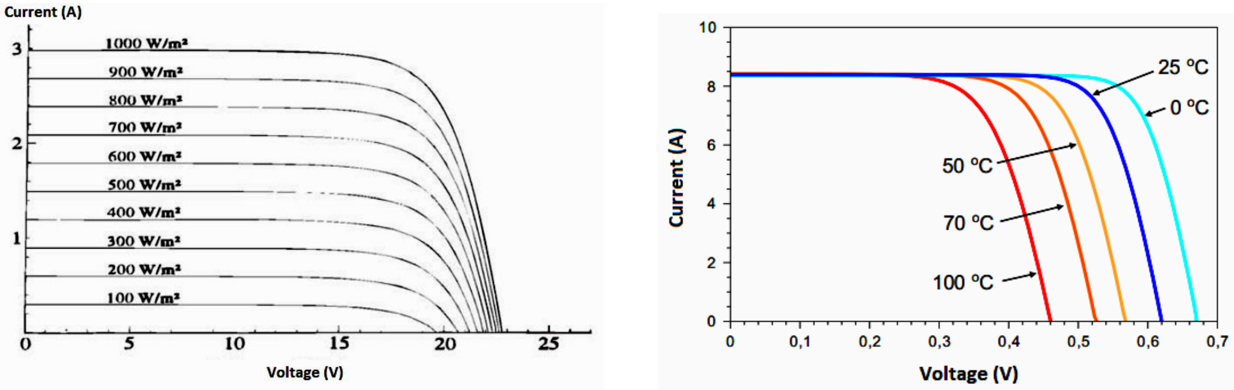
***Keywords:*** *PVT, Nanofluids, efficiency, non-concentration, review.*

## 1. INTRODUCTION

The world population has already reached 7.5 billion of people and the energetic demand only increases, which represent a problem since in 2015 almost 86 % of the world energy is of non-renewable origin (Samal Bex, 2016), and according to a research (Zou et al., 2016), non-renewable energy sources will be finished by the end of the 22st century. Distribution is another point of concern due to the differences in crust formation and evolution, fossil energy resources are distinctly distributed in regions around the world that creates an imbalance in exploration and production of energy (Zou et al., 2016). Therefore, increase the use of renewable energy sources as solar energy, wind power, hydroelectric power and geothermal energy is the key to supply the world energetic demand and ensure a sustainable future (Villalva, M. G. & Gazoli, 2012). Among the sources the solar energy is the most abundant on earth and can be explored for electrical and thermal energy (Moule, 2010).

According to the international energy agency (IEA) the capacity of renewable energy will increase by 50 % between 2019 and 2024, led by photovoltaic (PV) panels. Solar PV energy will represent almost 60 % of the growth. Thus, scientist worldwide seek develop technologies to make PV modules more attractive. Even though PV cells are an energy source promising, it is a low-efficiency energy that barely exceed 20%. (Torres, 2012) state that the main external features that influences PV cells power are solar irradiance and temperature.

PV module characteristic power increase with the increase of the solar radiation that attain the module surface, because the current generated is rises linearly with solar radiation, while the voltage does not change significantly as show Fig. 1a. Base on this concept, they are different methods focus in increase the PV power production by using a reflective or refractive optical devices (mirrors or lenses) to rise the amount of solar radiation received on the PV module surface. This is knowing as concentrated PV system. However, a high solar radiation causes an increase of the PV cell temperature that leads to a significantly drop of voltage, while the increase in current is negligible as show in Fig. 1b. In the literature, there are many studies that describe the relation between temperature and efficiency of a PV panel, however there is a generalized conclusion that an increase in temperature causes a considerable drop in the efficiency of electricity production (E. Radziemska, 2003). Thus, the efficiency of the PV module could be reduced at a rate of 0.40–0.6% for 1 K increment of module temperature (Rahman, Hasanuzzaman and Abd Rahim, 2015). This drop of efficiency due to the increase in the PV module temperature can be explained by the thermalization phenomena, which consists of electron collisions and gaps with the grid crystalline material due to the excess energy acquired by them during the photon absorption with energy greater than the gap of the semiconductor used. This energy from the solar irradiance, thus, is partially converted in output power and the rest is dissipated in the form of heat (Singulani, 2009).




(a) (b)

Figure 1. Characteristic curve of a PV module: (a) Effect of solar radiation. (b) Effect of temperature Adapted from (CRESESB, 2004).

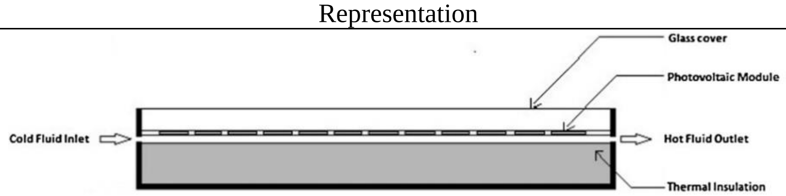
Hence, aiming to increase the PV panels efficiency, cooling methods base on the flow of fluids could be use and as these systems can produce simultaneously thermal and electrical energy, they are called hybrid photovoltaic thermal (PV/T) system. These type of cooling techniques can be divided in passive and active cooling. Evaporative cooling, phase change materials, submerged water cooling and heat pipes are the main passive methods. Among the active methods there are water spraying over or below PV module, jet impingement cooling and air or water flowing through a tube to cool the PV module (Elbreki et al., 2017). This paper is focus on the review and analyses of nanofluids flowing in pipes active method for cooling non concentrated PV modules.

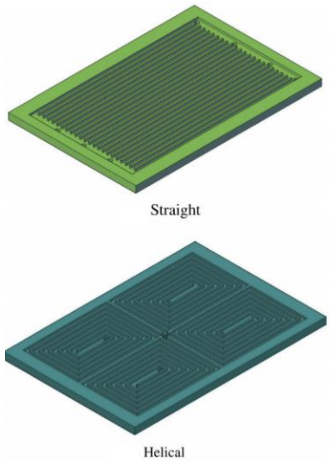
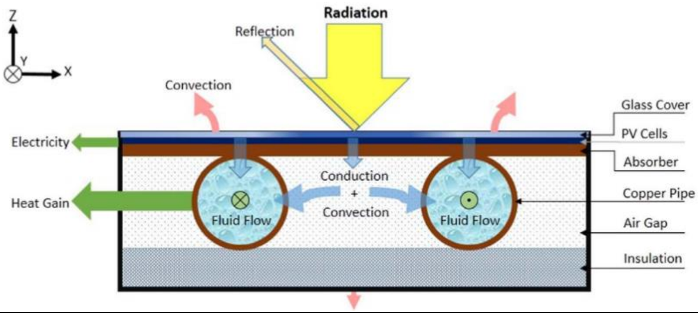
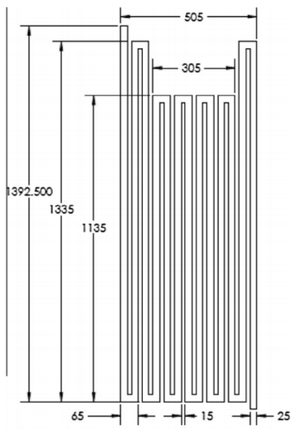
## 2. FLUID FLOW ACTIVE COOLING METOD

The method consists of a PV module and thermal collecting pipes, which are mounted to the back part of the PV module. A pump is utilized to force the passage of water in the pipes and the fluid is used as heat exchanger to extracting the heat of the PV/T collector. The heated water flows back to the hot water insulated tank for domestic or others applications (Elbreki et al., 2017; Siecker, Kusakana and Numbi, 2017). Important aspects of PV/T systems that directly impacts their performance are the collector's geometry and configuration and the working fluid utilized. It must be used an optimal configuration and geometry that enables extract the maximum heat possible of the PV cell (Hemmat Esfe, Kamyab and Valadkhani, 2020). The table 1 summarizes the main geometries and configurations in this kind of PV/T systems.

Water is the most common working fluid used to absorb the PV cells heat, and even proved to achieve significant efficiency improvement (Alzaabi et al, 2014), the search for fluids with properties that can enhance the PV/T systems efficiency even more, have been aim of several works worldwide. Nanofluids are one of the new age working fluids because of the remarkable thermophysical properties of them (Yazdanifard, Ameri and Ebrahimnia-Bajestan, 2017). A nanofluid is a fluid consisting of solid particles with size less than 100 nm suspended on it with solid volume fractions typically less than 4% (Prasher, Bhattacharya and Phelan, 2005). The properties of nanofluids are viscosity, specific heat, thermal conductivity and stability (Prasad, Singh and Nagar, 2017) and by changing the solid particle and the volume fraction it can be achieved different properties and optimize them according to the nanofluid application. Several works have been done for analyzing the performance of nanofluids as coolant fluid. This paper aim to review and summarize these nanofluids applications for cooling PV/T systems with different configuration and geometry and uses them as references for optimize the nanofluid and geometry choice for a future experimental work.

Table 1 – Representation of the main cooler geometries and configurations in PV/T systems.

| Geometry | Representation | Reference |
|---|---|---|
| Rectangular channel |   | (Michael and Iniyan, 2015) |

| | | |
|---|---|---|
| Microchannels |  | (Karami and Rahimi, 2014) |
| Sheet and Tube |  | (Sardarabadi et al, 2016) |
| Rectangular Tube |  | (Al-Shamani et al., 2016) |

## 2.1 Nanofluids aplicattion in fluid flow active cooling metod for PV modules

In the last decades, nanofluids have attracted the interest of the scientific community due to the expectation in enhancing the thermophysical properties. Mainly regarding anomalous gains in thermal conductivity as reported by Eastman et al., (2001) and Choi et al., (2001) where increases in thermal conductivity were obtained 40% and 150%, respectively for a dispersion of Cu nanoparticles in ethylene glycol and carbon nanotubes in oil, both with a fraction volume of less than 1%.

There are several types of materials used for the synthesis of nanofluids. In the literature, a large number of works can be found where carbon-based nanoparticles, the base of inorganic and organic materials and hybrid nanoparticles are used, with base fluids such as water, thermal oil, acetone, benzene and ethylene glycol (Cárdenas, 2019). In the work of Li et al, (2009) it is stated that all solid nanoparticles with high thermal conductivity can be used as additives for nanofluids.

However, there are other thermophysical properties involved in heat transfer processes, for which the addition of nanoparticles in the fluids is not too beneficial, including specific heat, specific mass and viscosity. Mahbubul (2019) conducted an extensive review of the works available in the literature dedicated to the study of these properties for nanofluids. However, most research reports improvements in the heat transfer coefficient using nanofluids in the most diverse applications (Assael et al., 2019) including PV cooling.

Sardarabadi et al., (2014) compared pure water and silica (SiO2)/water nanofluid 1% and 3% by weight (wt%). The work fluid circulates in copper tubes soldered on the back of the panel. The tubes are insulated and a pump ensure a constant flow rate. The working fluid is stored in a tank and pass by a sheet-and-tube heat exchanger to reduce his temperature, the second fluid used in the heat exchanger is running city water. The results show that the overall energy efficiency increase 3.6% on silica/water 1 wt% and 7.9% on silica/water 3 wt% when compared to water. Regarding thermal efficiency the daily average was 66.8%, 69.2% and 72.1% for pure water, and silica/water nanofluid 1 wt% and 3 wt%, respectively.

Michael and Iniyan, (2015) analyzed the performance of copper oxide/water as working fluid for PV/T system cooling. It was utilized a 0.05 % volume fraction of CuO/water nanofluid compared to pure water. The CuO/water nanofluid shown an increase in thermal efficiency up to 45.76 %. However, the electrical efficiency did not present a significant improvement. A PV/T glass-to-copper was made by laminating a copper sheet instead of the conventional tedlar layer. The new PV/T created had a thermal resistance reduce by 9.90 % compared to a convectional PV module. The back of the panel was covered by an aluminum sheet forming a water channel of depth 0.002 m, thus the channel holds the working fluid between the copper sheet and the aluminum and cools the PV cells. Furthermore, a glass thickness of 0.05 m was put as an insulation along the sides and back to reduce the heat losses.

Ghadiri et al., (2015) preformed and experimental investigation analyzing Fe3O4/water as working fluid to PV/T system cooled. It was compared distilled water and two different concentrations of Fe3O4/water (1 wt% and 3 wt%), besides the concentration, the nanofluid was submitted to different magnetic fields duo to their rheological and thermophysical properties be changed under an external magnetic field. The solar irradiation was simulated by nine tungsten halogen lamps each having 500 W and was provided two solar radiation condition, 1100 W/m2 and 600 W/m2. The working fluid after passing by the PV cells exchange the heat absorbed with running city water on a shell-and-tube heat exchanger, where it was put eight non-permanent magnets and with a magnet controller allowed to change the external magnetic field. The results show that distilled water as working fluid achieved an overall efficiency of 52 %. Changed to Fe3O4/water 3 wt% working fluid the overall efficiency was improved by about 76 %. Regarding the effect of alternating the magnetic field (50 Hz frequency) the overall efficiency was increase about 4-5 % to the same 3 wt% concentration and the thermal efficiency did not show a significant difference.

On an experimental and numerical study Sardarabadi and Passandideh-Fard (2016) tested three metal-oxides/water nanofluids as coolant in PV/T systems. The experiment consisted on circulate the work fluid in copper pipes and analyses its efficiency. It was used pure water, Al2O3/water, TiO2/water and ZnO/water as working fluids on a flow rate of 30 Kg/h and all nanofluids with a 0.2 wt% concentration. The numerical mode neglected ohmic losses of the solar cells, considered that the temperature of the fluid in the collector varies only in axial direction, assumed the sky a black body and that the fluid flow in the tubes uniform. The results compared to a PV without cooling system show an average increase on electrical efficiency around 5.48%, 6.54%, 6.46% and 6.36% for pure water, TiO2/water, ZnO/water and Al2O3/water, respectively. It was concluded on both numerical and experimental that the most significant effect using metal-oxide nanofluids was on thermal efficiency improvement. Among the nanofluids utilized the ZnO/water was found to be the one with better thermal performance. The numerical study was applied too, to analyze the effect of ZnO nanoparticle mass friction on the PV/T performance and it was found that with an increasing from 0.05 wt% to 10 wt% the thermal performance nearly increased by four times, but the electrical efficiency had a slight increase of 0.02 %.

On a similar work, Al-Shamani et al., (2016) investigated the performance of different types of nanofluids flowing in rectangular section pipes using two identical panels. The fluids in the PVT system, exchange the absorbed heat with water in a storage tank. It was analyzed water, and nanofluids base on $SiO_2$, $TiO_2$ and SiC as working fluids flowing at four different flow rates (0.068 kg/s, 0.102 kg/s, 0.136 kg/s and 0.170 kg/s). The authors concluded that the better performance was found with the SiC nanofluid, which achieve an energy coefficient (COE) of 0.93 and an electrical efficiency of 13.52% at a mass flow rate 0.170 Kg/s. The mean PV module temperature at the same flow rate for water, SiO2, TiO2 and SiC was 50.01 °C, 48.95 °C, 46.52 °C and 42.61 °C respectively.

Abdallah et al., (2018) compared the effect of water and Al2O3 – water on the performance of PV/T systems. It was used three identical solar cells, one submitted on water as coolant fluid, another with Al2O3 – water as coolant fluid and the other with no cooling method, the two PV/T system had a 5 liters storage tank. The Al2O3 – water was tested in five different concentrations of Al2O3 (0.05, 0.075, 0.1, 0.2, 0.3) %V. The cooling system was composed by a four paths copper pipe welded on the back of the panel. The results show that increasing the water flow to 1.2 l/min was reached the maximum combined efficiency of 40.9 % and 32 % at the maximum radiation and average across the day respectively. Regarding to Al2O3 – water the maximum combined efficiency was 74.17 % and 56.16 % at the maximum radiation and average across the day respectively on a concentration of 0.1 %V

Aberoumand et al., (2018) investigate the efficiency of Ag/water nanofluid compared with pure water as coolant in PV/T system compared. A pump was utilized for circulate the working fluid on a closed cycle, the fluid pass by a four path copper tube that was attached on the grooves of a copper plate made on a press machine. Besides the pump there is a radiator where the working fluid exchange the heat absorbed with water. It was analyzed two different concentrations of Ag (2 wt% and 4 wt%) for three different types of regime flow, laminar, transient and turbulent. The results show an improvement of 8 % to 10 % in the power output when water are replaced by Ag/water 4 wt%. An increase of 35 % in power output was achieved by using Ag/water 4 wt% on turbulent regime flow compared with a no cooling PV module. The exergy efficiency had an improvement when utilized Ag/water 4 wt% of 50 % and 30 % compared water as working fluid and no cooling method was utilized, respectively.

Abdallah et al., (2019) analyzed the performance of Multi-Walled Carbon Nano Tubes (MWCNT) water-based as coolant fluid on PV/T system. The experimental consist on compared the results of three identical PV cells. The first utilize water as coolant fluid on a flow rate of 1.2 l/min and a 5 liters storage tank. The second one utilize MECNT water-based as coolant fluid on five different concentrations (0.05, 0.075, 0.1, 0.2, 0.3) % V of (5:12) proportion with the based fluid. The other was a standalone PV cells with no cooling system. A four path serpentine shape of copper attached on a copper sheet was used as heat absorber on the PV panel back side. It was found that the optimum concentration was 0.075 %V which cause an average temperature reduction of 10.3 °C on the PV module leading to an overall efficiency of 61.23 %.

Alous et al., (2019) analyzed the performance of multi-walled carbon nanotubes (MWCNT) and graphene nanoplatelets, dispersed in water as base fluid, as coolant in PV/T system. Distilled water was utilized too as working fluid reference. The concentration analyzed of the nanofluids was 0.5 wt% with a flow rate of 0.5 l/min. The experimental consisted on two identical PV module, one submitted to a cooling system and other utilized as reference with no cooling system. The cooling system was composed by a heat exchanger formed by a thin copper plate where was welded a serpentine copper tubing, which was attached to the PV module back side. An insulation layer was put beneath the heat exchanger to reduce thermal losses. A pump was utilized to circulate the working fluid on a close circuit and besides the nanofluid tank there is a storage tank where the working fluid pass by a coil heat exchanger which utilize water to absorb the heat from the working fluid. The results show that MWCNT-water nanofluid presented a better performance on electrical energy conversion among the three working fluids, while in terms of thermal efficiency the graphene nanoplatelets-water nanofluid presented a better one. The total energetic efficiency enhancement achieved was 53.4 % for distilled water, 57.2 % for MWCNT-water and 63.1% for graphene nanoplatelets-water. The temperature reduction was 14 °C with distilled water, 14 °C with nanoplatelets nanofluid and 16 °C with MWCNT nanofluid. Regarding the exergy viewpoint, the total exergyc increase was around 11.2 %, 12.1 % and 20.6 % for distilled water, MWCNT-water and graphene nanoplatelets-water respectively.

Table 2 – Main works on nanofluid PVT application

| Author | Cooler geometry | Fluid Type | Highlights |
|---|---|---|---|
| Sardarabadi et al., 2014 | Sheet and Tube | $SiO_2$/water | ***** Concentrations of 1 wt% and 3 wt%<br>***** The overall energy efficiency increase 3.6% for 1 wt% and 7.9% for 3 wt%<br>***** Thermal efficiency achieved of 69.2% and 72.1%, for 1 wt% and 3 wt% respectively. |
| Michael and Iniyan, 2015 | Rectangular | CuO/water | * Rectangular channel of 2 mm.<br>* 0.05% volume fraction.<br>* Increased the thermal efficiency by 45.76% |
| Ghadiri et al., 2015 | Sheet and Tube | $Fe_3O_4$/water | * Concentrations of 1 wt% and 3 wt%.<br>* Compare to distilled water the overall efficiency of a Fe3O4/water 3 wt% was improved by 76%.<br>* With magnetic field the overall efficiency increases by 4-5%. |
| Sardarabadi and Passandideh-Fard, 2016 | Sheet and tube | $Al_2O_3$/water; $TiO_2$/water and ZnO/water | * Flow rate of 30 Kg/h and a concentration of 0.2 wt%.<br>* Increased the electrical efficiency around 5.48%, 6.54%, 6.46% and 6.36% for pure water, TiO2/water, ZnO/water and Al2O3/water, respectively. |
| Al-Shamani et al., 2016 | Rectangular Tube | $SiO_2$; $TiO_2$ and SiC | * Tube measurements: height of 15 mm, width of 25 mm and thickness of 1 mm.<br>* Four different flow rates ((0.068 kg/s, 0.102 kg/s, 0.136 kg/s and 0.170 kg/s).<br>* An COE of 0.93 and an electrical efficiency of 13.52% was achieved by SiC nanofluid with a 0.170 Kg/s flow rate. |

Continued next page

| | | | |
|---|---|---|---|
| Abdallah et al., 2018 | Sheet and tube | $Al_2O_3$ /water | * Flow rate utilized of 1.2 l/min and five different concentrations (0.05, 0.075, 0.1, 0.2, 0.3) %V. * The maximum combined efficiency achieved was 74.17 % on a 0.1 %V concentration. |
| Aberoumand et al., 2018 | Sheet and tube | Ag/water | * Concetrations of 2 wt% and 4 wt% for laminar, transient and turbulent regime flow. * Na increase of 35% in power output was achieved when utilized a 4 wt% and turbulent regime flow. * Improvement of 50% in exergy efficiency. |
| Abdallah et al., 2019 | Sheet and tube | MWCNT/water | * Utilized concentrations of 0.05, 0.075, 0.1, 0.2, 0.3 %V with (5:12) proportion with the based fluid. * The optimum concentrations was 0.075 which cause an temperature reduction of 10.3 °C and achieved an overall efficiency of 61.23%. |
| Alous et al., 2019 | Sheet and tube | MWCNT/water; Nanoplatelets/water | * Concentration of 0.5 wt% and a 0.5 l/min flow rate analyzed. * Exergy increase was around 11.2 %, 12.1 % and 20.6% for distilled water, MWCNT-water and nanoplatelets-water respectively. |

## 3. Conclusions

Renewable energies will play an important role in providing enough energy for humanity, as non-renewable sources will not last forever. It represents a broad transition involving distribution adaptation, efficiency, power quality, costs, etc. The improvement on these aspects of renewable energy have been aim of scientists worldwide. How efficient the energy is transformed in electricity it is a challenge that have been gradually overcome. It can be concluded in general through the works raised in this paper that significant improvements have been achieved in the efficiency of PV modules by dropping their temperature utilizing an active cooling method and, thereby, forming a PV/T system, capable of produce simultaneously thermal and electrical energy. Furthermore, analyzing nanofluids as coolant fluid it can be concluded that compare to water, they present a greater performance. It can be ensuring that there are many possibilities of different nanofluids, cooler geometry, particles concentrations, flow rate, etc and by doing experimental works it will be find optimal parameters to maximize PV/T systems performances.

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