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Comparison study of indoor/outdoor experiments of a photovoltaic thermal PV/T system containing SiC nanofluid as a coolant

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ABSTRACT

Solar energy technology has been evolving for the better part of the last decade. Worldwide innovation and support have created an alternative energy source that is helping to battle climate change. Photovoltaic thermal (PV/T) converters use various working fluids. Silicon carbide (SiC) nanofluid is employed in this study in the cooling application of a PV/T system. The aim of this study is to assess and evaluate the performance of PV/T collectors when running a SiC nanoparticle dispersed in water as the base fluid for both indoor and outdoor systems. The performance assessment includes thermal, electrical and combined PV/T efficiencies. Indoor and outdoor experimentation is done to accurately assess the performance enhancement hypothesized by the authors. Furthermore, a comparison is made between the indoor and outdoor results to validate each experiment and draw conclusions. The indoor system results were close to the outdoor experiment, suggesting a performance enhancement with an incremental efficiency rise.

1. Introduction

The solar energy market is growing rapidly around the world offering an energy alternative. Due to its renewable and clean nature, more people and governments are being encouraged to adopt this technology. Solar energy technology can involve photoelectric conversion or merely accelerated heat storage, in the form of photovoltaic panels and solar collectors, respectively. PV systems are implemented worldwide given that they produce electricity, and also that they do not need maintenance or create noise. The reason for the increased production and utilization of solar energy techniques is the major concern around fossil fuels, in particular their price fluctuations and harmful effect on the environment [1].

Between 2002 and 2015 the compound annual growth rate of PV panels was around 42%. China and Taiwan hold the highest percentages concerning annual global PV production, with around 67% and 52% in 2015. With regard to solar collectors, 410.2 GWth of installed capacity and 586.1 million square meters of collector area was in operation worldwide by the end of 2014 [2].

More research is being done to improve the efficiency and optimization of solar panels and solar collectors. The highest efficiencies for PV and solar collectors are achieved inside the laboratory, under controlled testing conditions. For PV panels, a record 46% efficiency can be achieved in the laboratory in high concentration multi-junction solar cells or 25.6% for a typical monocrystalline cell [3]. However, these values cannot be obtained in real life due to variable factors of degradation such as temperature, dust, wind speed and humidity [4,5]. The same problems are faced by solar thermal collectors where there are many reasons causing heat loss. One degree of validation is to examine mathematical (analytical/numerical) models with indoor experiments under controlled weather conditions, and another level of validation is to prove the product as a whole by examining it under real weather situations facing various sources of random variability and overall noise in the system. PV/T collectors combine the two technologies of PV and solar thermal collectors to produce higher thermal and electrical efficiencies [6]. This technique utilizes the concepts of thermodynamics where the collector is placed at the back of the PV panel to absorb its temperature, therefore, maintaining PV

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temperature, which ultimately protects the open circuit voltage and increases the collector's working fluid temperature to achieve higher thermal output [7]. In recent years, the use of nanofluid as a working fluid for PV/T systems has been studied.

Photovoltaic/thermal (PV/T) collectors combine the best aspects of solar photovoltaic panels and solar collectors to achieve maximum efficiency by utilizing more of the solar spectrum to produce both electricity and thermal energy [8–11]. The solar collector conducts heat from the PV panel through to the point of contact, helping to maintain the open circuit voltage [12]. The photovoltaic/thermal system uses a base-fluid within the tubes of the collector to increase the thermal efficiency. However, water may not be the most suitable fluid while nanofluids are being utilized in PV/T collectors for cooling purposes. Some factors contribute to the overall performance of the system at each stage. Firstly, the implementations of nanoparticles, which are highly dependent on size, shape, weight concentration and thermo-physical properties (i.e. viscosity, thermal conductivity, and density) [13], has been done before. As for the nanofluid, nanoparticles are mixed with water for a period of time to guarantee that no agglomeration or sedimentation forms [14]. The third stage is the nanofluid itself, which should be tested for stability, where Transmission Electron Microscopy (TEM) is used for such a purpose or Scanning Electron Microscopy (SEM) can be also employed in some studies to determine the size and shape of nanoparticles. The fourth process is the injection of the nanofluid into the system. Here, the mass flow rate makes a significant effect on heat losses and overall Photothermal conversion efficiency. The final step involves carrying out measurements and data collection to determine if there is a correlation between temperature, solar radiation, time and effectiveness, and then performing a comparison of these results. Several valuable review studies were conducted to discuss the main progress in this field [15–18].

In Ref. [19] an investigation on the effects of employing Cu_9S_5 nanofluid for an optical filter in a concentrating PV/T collector is described. The experiment was conducted outdoors on the rooftop of a building in China. The study shows how particle concentration, properties, and size can be used to enhance thermal conductivity. The study provided a statistic particle size distribution along with a transmission electron microscopy (TEM) image of the particles. The authors found an overall efficiency of 34.2% where an increase of 17.9% was achieved in comparison to when no filter was used (pervious condition). Moreover, the output temperature achieved exceeded 100 °C.

A comparison between a theoretical model and an outdoors experiment for a hybrid PV/T system using a beam splitting technique with a nanofluid composed of Ag-SiO_2 and water is described in Ref. [20]. The nanoparticle core-shell is suspended in water. The developed model was a prototype for optical and heat transfer. The system is composed of a Fresnel lens, transparent channel, heat transfer fluid and a mono-crystalline PV strip array. The authors claimed that the advantage of such a design is that the nanofluids extend to being the standard heat transfer fluid and spectral selective absorbing fluid. The study links thermal output as a function of concentration ratio, where the relationship is found to be directly proportional. Four different concentrations of nanoparticles in nanofluids were tested. The electrical model showed a decrease to 27 W/m^2 with increasing nanoparticle concentration. The importance of this study lies in comparison; it shows how to implement theoretical models and experimental tests as well as the comparison of results. In Ref. [21], a model and experiments undertaken on a nanofluid filter (of various particles) that is located between a silicon cell and a light source is described. The nanofluid consists of core-shells of silver-silica nano-discs (Ag-SiO_2) and carbon nanotubes (CNT), which are both suspended in water. The nanofluid enhanced the overall efficiency by 30%. The study presents nine nanofluid solutions and shows a comparison between each, to serve the splitting technique. The merit function of each fluid was examined, and at relative worth factor $W = 3$, the highest figure of merit was sample Ag1 containing Ag-SiO_2 with the concentration of 0.026%. This results in an electrical efficiency of 9% and a thermal efficiency of 60%.

The use of nanofluids to cool PV/T collectors and enhance electrical and thermal efficiencies using a base-fluid of water and silica is proposed by Ref. [22]. The study suggests using two 1% and 3% weight concentrations. The experiment was conducted to compare the different elements of the system, namely, the conventional PV systems and PV/T collectors, and also the water-based PV/T collector and nanofluid-based PV/T collector. Finally, a comparison was conducted between 1 and 3% weight concentrations of Silica/water SiO_2 nanofluids. As expected from the mathematical and theoretical study, the experimental results shows a total PV exergy of 19.36% when using pure water. Moreover, an exergies of 22.61% and 24.31% for 1% and 3% weighted concentrations of SiO_2 respectively, were achieved. Furthermore, the study aimed to optimize mass flow rates by taking three different rates (20, 30 and 40 L\h) as the working fluid. The optimum mass flow rate of the working fluid was found to be 30 L per hour while the mass flow rate suitable for city water is 40 L per hour. The maximum efficiency increase found in this study is around 12.8% when using a 3% weight percentage of nanofluid, while a 7.6% increase was found when using 1%.

The effects of variable elements of direct absorption solar collectors on efficiency, such as the volume function of the nanoparticle, height of collectors, solar flux, and nanoparticle material are analysed in Ref. [23]. With Maxwell and energy equations developed, the analysis involved one-dimensional transient heat transfer. The authors used K-type thermocouple sensors to simulate solar radiation and a data logger was connected to the system to collect data. Two models were presented for the sake of temperature distribution comparisons. The results illustrate the effects of each element. Efficiency will increase with increasing collector's height and nanoparticle volume fraction while it decreases corresponding to longer irradiation time. Over the wide temperature range, it is preferred to have a high solar flux. This study only focuses on the collector as there is no mention of photovoltaic cells or PV/T. However, this study is still important as it shows how nanoparticles affect thermo-physical properties as well as the mixing process.

The author of reference [24] performed an experiment on volumetric solar collectors using graphene nano-platelets/deionized water by trying different weight fractions, various inlet temperatures, and three mass flow rates. The collector efficiency increased with an increase in the weight fraction of the nanofluid, with a maximum achieved efficiency of 93.2% for a 0.005 wt fraction at a 0.015 kg/s flow rate.

Ref [25] analytically and experimentally investigated the effect of CuO/water nanofluid as a base technique. The experimental results served to validate the results of the developed model. The system is composed of a parabolic section, a reflector, and an absorber tube. The investigation shows a decrease in heat loss which is attributed to increasing mass flow rates. Ref. [26] described an experiment on PV/T collectors (unglazed-flat-plate) to determine the enhancement in electrical and thermal efficiencies. The study used an RTD PT-100 thermocouple for temperature measurements. The outdoor experiment resulted in an electrical efficiency of 12.77% and a thermal efficiency of 35.33%, which is relatively acceptable. The authors did not go into further detail about the environmental aspects of the location.