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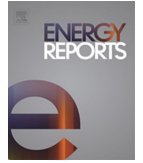
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Graphene Nanoparticles (GNP) nanofluids as key cooling media on a flat solar panel through micro-sized channels

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Abstract

Typically, in a solar-to-electricity energy conversion process from a PV solar panel, this mechanism often accompanied with a creation of by-products which refers to unproductive heat on the surface of PV solar panel. This unwanted heat energy produced will lead to reduction of total effective output of electrical parameters due to the negative inversely proportional relationship between PV temperature and output efficiency. Therefore, it is important to cool the temperature of PV panel relatively in optimizing the output efficiency. This paper is focusing on using state-of-arts nano-sized materials (graphene particles (GNP) in a liquid solution) to achieve the cooling desired. In the previous simulation research carried out on the similar subject, it was found that by having multiple channels with equal volume, the cooling effects will be peaked using graphene nanofluids. This paper presents the experimental setup and fabrication methods using GNP nanofluids as key media in studying the effectiveness of GNP in cooling of a flat solar panel through continuous flowing of GNP nanofluids inside multiple micro-sized channels which were made in direct contact with the exposed backside of the PV solar panel. It is expected that GNP with its enhanced thermo-physical properties compared to water, the cooling efficiency will increase subsequently. Cooling effects due to different pumping flowrates were also being studied respectively.

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Keywords: Nanofluids; Solar panel cooling; Graphene Nanoparticles (GNP); Micro-sized channels

1. Introduction

This paper provides the experimental results of using Graphene Nanofluids (GNP) as key Cooling Media through micro-sized channels that being placed to be in a direct contact mode on the backside of a PV solar panel to probe the effectiveness of cooling. This combination of methods is expected to reduce the PV solar panel's surface temperature and increase output efficiency.

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2. Literature review

In the search of accomplishing the “holy grail” method in increasing the output efficiency of solar panels other than downsizing the cost and using different Transition Metal Group materials, several researches been done on cooling of solar panel in order to enhance the performance of PV panels. An experimental setup design of the cooling system which primarily done by circulating water around the PV solar panels, it increases the output power by nearly 50% relatively [1]. Their methodology is rather simple as it started with the water pump which draws the water from the tank filled with water. Other researchers noticed that the efficiency peaked at lowest operational temperature when temperature was varied up to 75 °C [2]. In addition, a comprehensive review and research on cooling techniques by using water as cooling media was carried out by Moharram et al. [3]. One of the most prevalent technique used by researchers on cooling of PV solar panel is Hybrid Photovoltaic/Thermal (PV/T) solar system at which this method consists of a cooling system attached with the PV solar panel with water and air as cooling agent circulated respectively [4]. It is then pass through the filter and the nozzle will then spray the water onto the surface of the PV module. The team stated that by this approach, the reported cooling rate of approximately 2 °C/min was achieved. Although this method has high efficiency in cooling rate, it comes with disadvantages with space management especially when installing the PV solar panel system on the rooftop as the whole setup will be huge and impractical. Another cooling method applied to cool the PV solar panel was by using pool-like concept [5]. In this approach, the solar panel were placed on different level (depth) inside a small tank filled with varying cooling media aka to a small/tiny solar farm on top of the roof. He reported this technique would be quite efficient to cool down the temperature from more than 65 °C to around 45 °C in all cases. Similarly, the disadvantages of this approach are that not only a large setup is needed, the setup would be expensive and impractical to be installed on rooftop.

Nanofluids are fluids with the mixture of nanoparticles and base fluids with nanometer-sized (1–100 nm in one dimension). The huge motivation behind the idea of using nanofluids as the key agent in cooling is due to the fact that nanometer-size particles have a large surface area to volume ratio which simply means higher percentage of surface area of nanoparticles are available to be used/manipulated and positively compounded by their smaller size which literally mean higher density/concentration of particles could fit in a cubic volume, the cooling effect would be tremendously enhanced [6]. Numerical simulation of silicon solar cell by forced convection in the presence of Al₂O₃-Water nanofluids was studied with respect to the increasing the concentration of nanofluids from 0% to 10% [7]. Convincingly, he reported that the heat transfer rate increased by 27% which further suggested that the use of nanofluids is justly justified. In another work, graphene oxide nanofluids was investigated in relation to their enhanced heat-exchange capability, thermophysical and quantum properties in comparison with water [8].

3. Channels fabrication & graphene nanofluids preparation

Fabrication of the micro-size multi-channel fabrication was done through moulding technique using Polydimethylsiloxane (PDMS) with ratio of 1:10. All channels (12 channels) have top rounded-rectangular shape with designated width of 258 mm, length of 330 mm, height equals to 10 mm and the spacing between each channel is 10 mm. Room temperature curing was preferred in this case as the mask will have less shrinkage compared to curing at 70 °C in the oven. Total volume of the channels are estimated to be 346.5 cm³. From the inspection, bubbles were seen but not detected on the surface of all channels which potentially could lead to clogging of nanoparticles during experiment. These bubbles issue were created during stirring process and could be solved by degassing of the PDMS mixtures before the curing step. In preparing the graphene nanofluids for this study, we followed the published procedure by Devireddy et al. [9]. Graphene nanoplatelets with surface area of 750 m²/g surface area was purchased and used from Sigma-Aldrich. The stability of the nanofluids can be further enhanced by ultrasonic dispersion. Next, total amount of nanoplatelets required were estimated accordingly which is corresponded to 76.23 gram of nanoplatelets (True density of Graphene nanoplatelets = 0.22 g/cm³). 1 liter of de-ionized water was used to mix the weighted nanoplatelets before being mixed evenly using a magnetic stirrer. Next, ultrasonication process was carried out continuously for 2–3 h to make sure that there will be no significant in term of dispersion.

4. Experimental setup and testing

Experimental setup was carried out using customized-setting to mimic actual operating condition. To represent the function of a solar source or continuous solar irradiance over certain amount of times, 4 LED light bulbs, Philips,

40 W were lined-up in the manner that cover the whole PV solar panel. The working distance between these light sources with the PV solar panel is 15 cm separated apart. PV Analyzer, PROVA 200A was used to continuously capture the PV solar efficiencies and correspondence electrical parameters. Altogether, three (3) different data set (each set has 32 data points) were measured individually for each of the testing conditions, providing a total of 96 data points for solar irradiances as well as for surface temperature measurement respectively. Cooling down of the panel was observed for at least 8 h before initiating a new testing cycle for all experiments. Two testing modes were carried out which were with continuous external pumping and without pumping. Discussion resolving non-pumping or without pumping shall be referred as non-cooling. As for the external pumping testing, shall be referred as cooling with water and cooling with graphene nanofluids respectively. The flowrate was monitored through ARDUINO controller in continuous and online conditions. For the testing of cooling with water and graphene nanofluids, two flow rates were tested which were 1.11 m/s and 0.44 m/s which was the maximum and minimum flowrates the setup could reached practically.

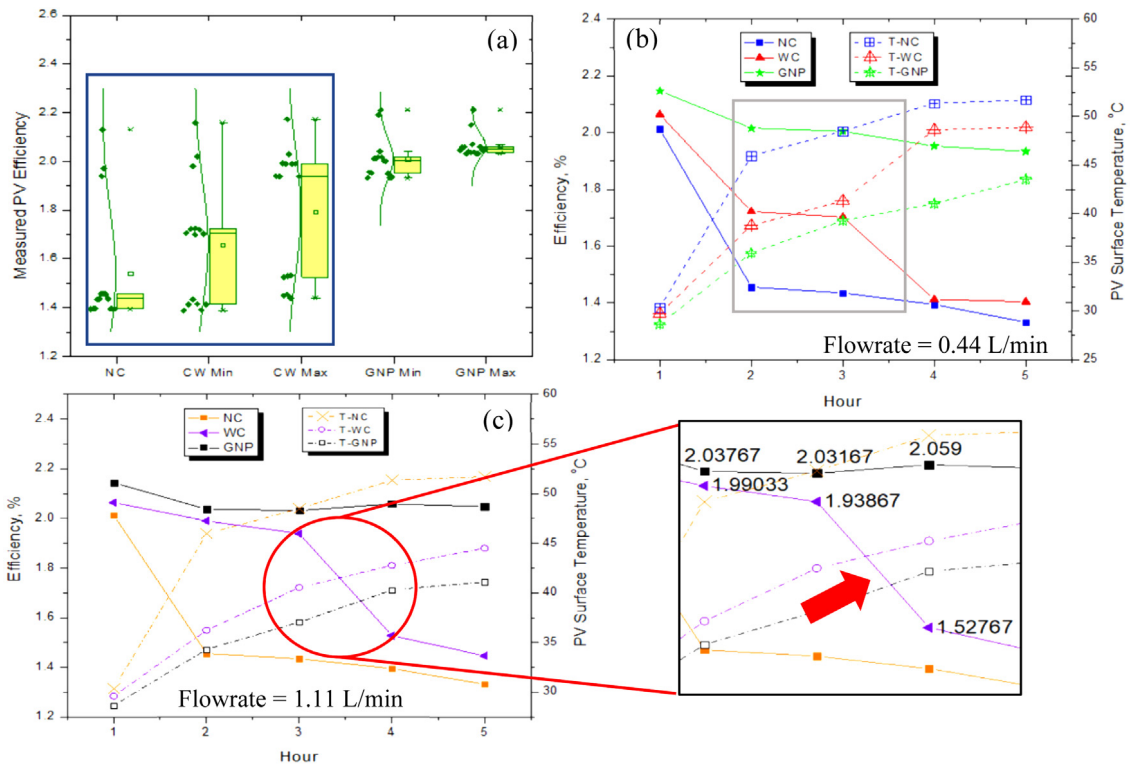


Fig. 1. Measured PV efficiency under different pumping flowrates and cooling media. (a) Box Chart showing overall measured data on PV efficiency vs. different testing conditions. (b) Line graph showing relationship and efficiency trend of the PV solar panel under minimum pumping flowrate of 0.44 L/min. The corresponding surface temperature is plotted on secondary Y-axis of the right hand side of this plot. (c) Another line graph highlighting the efficiency trend of PV solar panel under maximum pumping flowrate of 1.11 L/min with a circle showing efficiency drops for cooling with water case but opposite observation was noticed for GNP nanofluids cooling.

5. Result & discussion

Efficiency of the PV Solar panel under test was measured using PV analyzer (PROVA 200A, Taiwan) for each individual testing condition in-situ during the experiment for 5 h under continuous solar irradiances. A total of 15 distinct and different independent set of data points were measured accordingly for each testing conditions. Fig. 1(a) summarizes all the data measured and corresponding measured operative temperature. From the plot, measured PV efficiency is generally increases when experimental condition switches from Non-cooling to cooling with water and subsequently cooling with GNP nanofluids. It is worthwhile to note that the scattering of data in GNP nanofluids cooling is less compared to Non-cooling (NC) and cooling with water (CW) for both min and max flowrates. This is

due to the fact that PV panel efficiency decreases when temperature is above 45 °C as per reported in the literature. This phenomena could be primarily seen in the case of Non-cooling and Cooling with Water but less significant for GNP nanofluids as highlighted with a box in Fig. 1(a).

In order to study in-depth of this relationship, both efficiency and its corresponding temperature gauged hourly under constant pumping flowrate and solar irradiance were plotted on a two Y-axes graph for non-cooling, cooling with water and cooling with GNP nanofluids as per Fig. 1(b). It is observed that the general trend concurs well with the literatures. Between the first hour and second hour of testing, due to the constant solar irradiances on the PV, temperature of the PV started to increase dramatically to over 40 °C to 45 °C from less than 30 °C as per indicated in Fig. 1(b). Respectively, the efficiency measured started to drop dramatically for both non-cooling and cooling with water cases. However, in the case of GNP nanofluids as cooling media, the temperature measured is still less than 45 °C. After the second hours, for non-cooling and cooling with water, efficiency continues to drop gradually. Nevertheless, efficiency for cooling with water encountered second significant drop between third hour and fourth hour before reaching plateau-like line compounded by a spike in its corresponding measured temperature on the PV panel. Where-else, for the non-cooling case, efficiency stumble upon a more gradual decrease with the final resting temperature reaching around 52 °C.

Overall trend and relationship for cooling with GNP nanofluids shows opposite effect with the temperature measured are well controlled between room temperature to optimum operative temperature which is less than 45 °C. It is observed that the results follow general trend as per exhibited in the minimum flowrate (0.44 L/min) testing but with higher magnitude or quantum outcomes where efficiency decreases whenever the temperature is high (over 45 °C). Overall temperature for both cases (cooling with water and GNP Nanofluids cooling) in this maximum flowrate (1.11 L/min) remain lower than 45 °C. While operating temperature remains lower than 45 °C, it is expected that the efficiency in the case of water cooling to be remain competitive but this is not seen relatively as per Fig. 1(c). Moreover, it is significant to note that the efficiency for water cooling between third and fourth hour drops tremendously from around 2% to 1.5% and this is not observed in the case of GNP Nanofluids cooling where its efficiency over last four hours remains rather flat or no-significant change. This occurrence is highlighted with a circle on Fig. 1(c).

Table 1. Relative comparison between average efficiency between cooling with water compared to non-cooling and GNP nanofluids cooling with non-cooling and cooling with water for both min and max flowrates.

Hour	Flowrate: 0.44 L/min			Flowrate: 1.11 L/min		
	WC/NC (%)	GNP/NC (%)	GNP/WC (%)	WC/NC (%)	GNP/NC (%)	GNP/WC (%)
1	2.52	6.64	4.02	2.52	6.47	3.86
2	18.30	38.47	17.05	36.73	39.98	2.38
3	18.66	39.71	17.74	35.13	41.61	4.80
4	1.27	40.04	38.29	9.56	47.67	34.78
5	5.41	45.17	37.73	8.58	53.73	41.58

Note: WC: Water Cooling, NC: Non-cooling, GNP: Graphene Nanoparticles Nanofluids Cooling.

To investigate further on effectiveness of cooling by water and GNP nanofluids, relative comparison of hourly efficiency was recorded and studied for 5 h in continuous manner and the results were listed in Table 1. As for the minimum flowrate of 0.44 L/min, the results show that in comparison between average efficiency of water cooling with respect to non-cooling, maximum average efficiency is 18.66% recorded within the first three hours of testing and the efficiency drops to only 5.41% for the last hour. Meanwhile, for the similar flowrate, GNP cooling exhibits quite positive increase of efficiency with maximum efficiency of 45% at the last hour. In a relative evaluation, it is estimated that GNP nanofluids cooling has higher affinity in optimizing the performance of the PV Solar panel that is tested under constant solar irradiances by 37% compared to testing carried out under water cooling for 0.44 L/min flowrate. This is shown in Table 1 respectively. As for the maximum flowrate of 1.11 L/min, both water cooling and GNP nanofluids cooling show positive and higher gain in term of average efficiency measured with max values stated at 50% increase for water cooling and 19% increase respectively compared to 0.44 L/min flowrate. In addition, it is estimated that with the highest flowrate, GNP nanofluids cooling shows highest effective efficiency gauged at roughly 42% compared to water cooling. This study suggests and demonstrated that GNP nanofluids exhibits better cooling capability and as superior cooling agent/media compared to water as well as non-cooling cases in this experiment.

6. Conclusion

This study found that GNP nanofluids cooling shows highest effective efficiency gauged at roughly 42% compared to water cooling with solution being flowed at 1.11 L/min flowrate and 54% increase if compared to non-cooling while operating temperature is less than 45 °C. This study demonstrates a strong and credible potential of applying GNP nanofluids in backside cooling of solar panel to enhance the operation and achieving higher efficiency of the panel using micro-sized channels. In the future, different flowrates shall be studied extensively.

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