Effect of nanofluid concentration on the performance of PV/T collector under the tropical climate of Indonesia

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Abstract

Solar energy is a very potential and most abundant source energy available and it is free of cost in consuming this type of energy. Flat plate solar collector is a device that can transform solar energy into the thermal energy and can be implemented to PV/T solar collector. In this study, a modified flat-plate PV/T solar collector was built by attaching the thermal collector underneath the PV collector surface. The application of nanofluid in the PV/T solar collector as a heat-absorbing medium needs to be developed and characterized in different environments condition. The effect of nanofluid concentration on the performance of the PV/T collector was investigated according to EN 12975-2 standard. The volume fraction of the nanoparticles used in the present study were 0.3%, 0.6% and 0.9%, respectively. The efficiency of the system was compared to the water as a base fluid performed in low latitude tropical region (Bandar Lampung climate). The experimental result shows that an increase of zero thermal efficiency up to 18% which is obtained by using nanofluid at the volume fraction of 0,9%.

Keywords: Solar, collector, PV/T, nanofluid, PV/T, tropical

1. Introduction

The sun is a renewable energy source that has several advantages such as being easily available, free of pollution and available in considerable quantities. A flat plate solar thermal collector is a device used to harness solar energy. This type collector is widely used to absorb solar radiation and transform it into heat energy which produces domestic hot water. In other applications, this type collector also can be implemented to absorb the excess heat collected on the surface of solar cell (Photovoltaic). Therefore, the attaching the two surfaces between the thermal collectors and the solar cells is a good way to solve the problem with respect to the excess heat on the solar cell surface. In particular, this type collector is called as a hybrid Photovoltaic/Thermal (PV/T) collector.

The PV/T collector can generate thermal and electricity energy simultaneously. Another advantage of using this type of collector is that the electrical efficiency remains stable even increases due to absorbing the excess heat by the working fluid on the surface temperature of the PV. Besides producing electricity, the PV/T collectors also produce hot working fluid so that they can be used for various purposes such as the heating process in industry and the health sector, household needs and other needs. Investigations have been carried out and reported over the last 25 years by several researchers (Abdelrazik et al. 2018, Amrizal et al. 2010, 2012, 2013, 2017) those are related to the evaluation of thermal and electrical output. They present experimental work, analytical, numerical models, simulation and the development of performance testing processes.

Concerning to the traditional working fluids of the PV/T solar collector, in fact, water or oil based fluids used in the PV/T collector have low thermophysical properties in term of thermal conductivity and specific heat capacity. Nanofluid shall be alternatively applied to this type collector in enhancing the performance of the collector. In this context, Das et al. (2006) introduced nanofluid that contain a small quantity of nanoparticles which have diameter usually less than 100 nm. It is mixed with conventional fluids providing more heat transfer ability. The solid particle dispersed in base fluid such as thermal oils, refrigerant, ethylene glycol or water (Yazdanifardet et.al 2017, Bellos et al. 2018, Khanafer and Vafai 2018. This could be important because by implementing nanofluid, the heat transfer of the fluid can be increased significantly (Mahbubul, 2019).

Significant findings have obtained by several researchers for metal oxide nanoparticles added into different base fluids which are called it as nanofluids. Sardarabadi and Passandideh (2016) presented an experimental study and a numerical of a PV/T collector with several types of nanoparticles. Al_2O_3, TiO2 and ZnO are used in this study were as nanofluids. The authors concluded that ZnO nanofluid and TiO2 nanofluid have the higher electrical efficiency than Al_2O_3 nanofluid.

Hashim et al. (2015) conducted an experimental work of the effect of using Al_2O_3 nanofluid as a cooling medium for the PVT collector system based on forced convection. Several different concentrations of Al_2O_3 nanofluid were tested (0.1, 0.2, 0.3, 0.4 and 0.5%). The results show that the temperature decreased significantly to 42.2°C and the electrical efficiency increase 12.1% at a concentration of 0.3%.

The experimental and numerical studies of a PVT system cooled by nanofluids was introduced by Rejeb et al. (2016). Nanoparticles (Al_2O_3 and Cu) are tested by the authors at three different concentrations (0.1, 0.2, and 0.4 wt %) with fluids (ethylene glycol and water) on the performance of the system. The results show that the thermal and electrical efficiencies of water as a base fluid is more effective than ethylene glycol.

Concerning several literatures, they studied the size, arrangement, location, and type of fluid used for cooling in PV/T collector. However, studies by using nanofluid as a coolant under the tropical climate is still limited in Indonesia, for that it is necessary to investigate the behavior of the PV/T collector in the present study since it enhances heat transfer process substantially.

2. Experimental methods

The collector utilized in this work was performed by attaching the solar thermal collector under the surface of PV cell as presented in Figure 1. This type collector was tested in Bandarlampung, at the Department of Mechanical Engineering, Universitas Lampung – Indonesia. Bandarlampung is the capital of the Lampung Province, Indonesia and the geographical coordinates are 5.25 °S and 105.17 °E. The Bandarlampung zone has a typical tropical climate which is characterized as dry and rainy seasons. The effect of nanofluid concentration on the thermal performance was investigated according to EN 12975-2 (2006) standard. The volume fraction of the nanoparticles used in the present study were 0.3%, 0.6% and 0.9%, respectively. The performance of the system was compared to the water as a traditional working fluid performed under low latitude tropical region (Bandar Lampung climate) and the average ambient temperature of 27 ^{o}C.

2.1. Experimental procedures

The collector must be tested under incident radiation more than 500 W/m^2. Data collection were recorded for inlet and outlet fluid temperatures, ambient temperature and incident radiation, respectively. Then, the temperatures and radiation were measured using K-type Thermocouples and Solar Power Meter SPM 1116SD, respectively. According to EN 12975-2 standard, the mass flow rate of the working fluid was regulated by using a valve at a constant flow rate of 0.02 kg/m^{2}s. Electrical heaters were used in order to vary inlet fluid temperatures during the tests.

Fig. 1: PV/T collector

2.2. Characterization of PV/T solar collector

In generally, equations of solar thermal collector performance are given as follows.

$$q_u = F^{'}[(\tau\alpha)G \quad - U_L(T_m - T_a)] \tag{1}$$

$$q_u = \dot{m}c_p(T_m - T_a)/A_c \tag{2}$$

The above equations are based on the energy balance in which equation (1) is known as The Hottel-Whillier-Bliss equation (Dufie et al. 2006) where $F^{'}(\tau\alpha)$ is the zero loss efficiency, $F^{'}U_L$ is the overall heat loss coefficient, respectively. From equation (2) $\dot{m}$ is the mass flow rate of fluid, c_p is the heat capacity of fluid, $(T_m - T_a)$ is the temperature difference and A_c is the area of absorber plate. Furthermore, electrical efficiency of the PV/T collector is obtained from equation 3

$$\eta = \frac{P}{GA} \tag{3}$$

where P is electrical power given by PV/T collector during the tests (P = VI), G is solar radiation and A is area of the collector.

3. Result and Discussion

Several performance tests were conducted in relation to the different nanofluid volume fraction and the inlet fluid temperature, respectively. Table 1 presents the results of the surface temperature and electrical power. Furthermore, the electrical efficiency is shown in Figure 2. Four types of working fluid were implemented such as water only and three different concentrations of TiO_2 nanofluid.

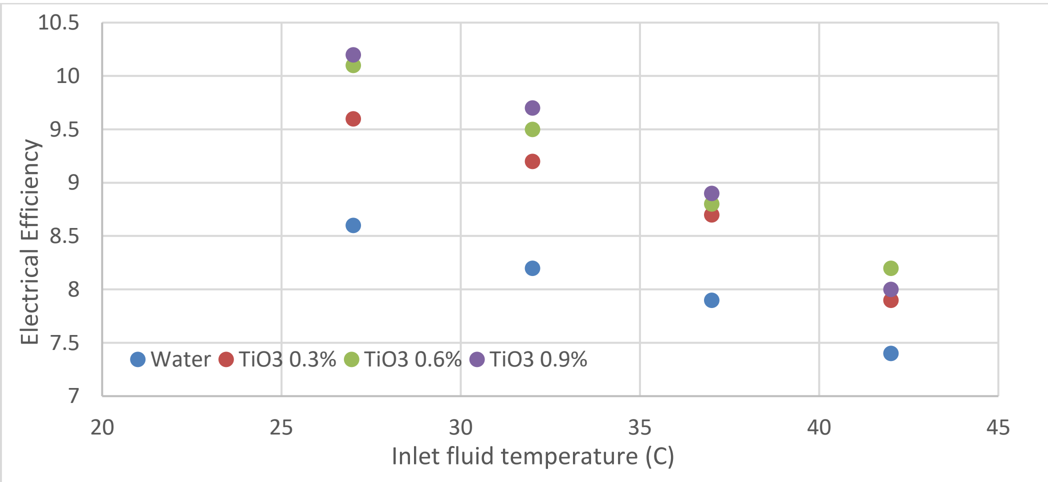

Fig. 2: Electrical efficiency versus inlet fluid temperature

Concerning the thermal performance in the current work, it describes the effect of water and TiO_2 nanofluid as a base fluid with different nanofluid volume fraction. The values of zero thermal efficiency parameter are 0.58, 0.71, 0.68, 0.66, 0.65 for water, TiO_2 nanofluid 0.3%, TiO_2 nanofluid 0.6%, TiO_2 nanofluid 0.9%, respectively. In comparison with the water only, there is an increase of zero thermal efficiency ($F'(\tau\alpha)_e$) up to 18% which is obtained by using nanofluid at the volume fraction of 0,9%. The significant different between the two results with and without nanofluid because of the heat transfer can be increased as well as the thermal performance of the whole system. Consequently, the nanofluid absorb more heat than that of the conventional fluid water.

In term of the electrical performance, as shown in Figure 2 the surface temperature of PV collector with 0.9% of TiO_2 nanofluid has lowest value in comparison with the others. Consequently, this might give the highest value of electrical efficiency about 10.2 %. Therefore, the nanofluid implemented on the PV/T collector has better thermal performance than the water only as a base fluid. In case of increasing the concentration in the current work, it does not significantly affect the electrical efficiency of the PV/T solar collector with respect to each others. The values for electrical power from different volume fraction of the TiO_2 nanofluid are almost constant and a small different is given in the values for electrical efficiency.

Table 1: average temperature of the PV surface and power based on the inlet fluid temperature different concentration of TiO_2 nanofluid

Inlet Fluid Temperature (^0C)	Water only		TiO_2 nanofluid (0,3%)		TiO_2 nanofluid (0,6%)		TiO_2 nanofluid (0,9%)	
	T_s (^0C)	Power (W)	T_s (^0C)	Power (W)	T_s (^0C)	Power (W)	T_s (^0C)	Power (W)
27	59,36	31,22	57,80	35,79	55,60	36,33	53,5	36,75
32	62,82	29,60	60,80	33,69	58,70	34,19	56,6	34,90
37	66,30	28,38	63,62	31,50	62,20	31,86	60,2	32,51
42	70,35	27,20	68,81	28,83	66,60	29,38	64,15	29,91

*T_s (C) : average temperature of the PV surface

4. Conclusion

Effect of nanofluid concentration on the behavior of PV/T flat-plate solar collectors has been characterized. The parameters that characterize the PV/T collector are zero thermal efficiency, the overall heat loss coefficient, average temperature of the PV surface and electrical efficiency. The performance of the system was compared to the water as a base fluid implemented in low latitude tropical region (Bandar Lampung climate). The experimental result shows that an increase of zero thermal efficiency up to 18% which is obtained by using nanofluid at the volume fraction of 0,9%. Furthurmore, the surface temperature of PV collector with 0.9% of TiO_2 nanofluid has lowest value in comparison with the others. The TiO_2 nanofluid absorbs more heat than that of the conventional fluid water. However, the values for electrical power from different volume fraction of the TiO_2 nanofluid are almost constant.

5. Nomenclature

F' collector efficiency factor m^2
G solar radiation W/m^2
T temperature C
$\dot{m}$ mass flow rate kg/s
q energy gain W
k thermal conductivity W/mC
c heat specific of fluid J/kgC
U overall heat loss coefficient W/m^2C
A area m^2
V Voltage V
I current Ampere

Greek letters

α absorbtivity -
τ transmissivity -

Subscripts

a ambient
m mean
s surface
u usefull
p pressure

6. Acknowledgements

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