EXPERIMENTAL ANALYSIS ON THE PERFORMANCE OF PHOTOVOLTAIC MODULE WITH Al_2O_3 DEIONIZED WATER NANOFLUID

by

Srilasri MUNIYANDI*[*] *and Stalin NARAYANASAMY

Department of Petrochemical Technology, University College of Engineering - BIT Campus,
Tiruchirapalli, Tamil Nadu, India

Original scientific paper
https://doi.org/10.2298/TSCI230829268M

The demand for energy is increasing across the globe for several economic growth-related activities which are mostly obtained through fossil fuel. It results in adverse effects on the environment in the form of increased GHG emissions. Most countries are formulating green energy policies to reduce the impact of fossil fuels. Solar energy is one of the most preferred renewable sources to meet the energy requirement which are harvested using the PV system. However, the major limitation of the PV system is that its performance decline at higher operating temperature. For cooling the PV systems, several researches are carried out and still the problem persists. In the present work, the alumina nanofluid is synthesized using deionized water as the base fluid and used as the coolant for the PV module. The concentration of Al_2O_3 *in deionized water is varied from 0.01-0.04% with a varying flow rate of 10-60 Lph. The impact of the* Al_2O_3 *nanofluid on the performance of the PV module is studied in terms of overall efficiency, and thermal and electrical efficiency. From the observed results, it is evident that the usage of* Al_2O_3 *nanofluid enhanced the efficiencies of the PV module in comparison with base deionized water. The optimum flow rate for* Al_2O_3 *nanofluid is observed to be 40 Lph when the concentration is about 0.04%.*

Key words*: PV module,* Al_2O_3*, nanofluid, efficiency, deionized water*

Introduction

The demand for energy is increasing worldwide for several economic development activities which increase the consumption of fossil fuels. This resulted in rapid depletion of fossil fuels across the globe and it increased the emission of harmful GHG into the environment. Many countries are attempting to reduce the usage of fossil fuels and replace it with renewable sources. Solar energy is one of the most abundant green energy available globally to meet the energy demands [1]. Nearly, 174000 TW of solar energy is available in the atmosphere that can be harvested through the available technologies. The harvesting of solar energy is carried out through different forms such as thermal, electricity, chemical, and conversion processes of photothermal energy to collect the heat. However, the existing technologies are less effective in harvesting solar energy [2]. The solar energy harvesting is generally carried out through the

---

[*] Corresponding author, e-mail: srilasri21101983@gmail.com

solar thermal collectors and PV systems. The PV systems are employed for the generation of electricity and their efficiency is about 15-17% only. The efficiency of the PV systems or modules can be improved by maintaining the temperature of the PV panel at the optimum range through the usage of coolants [3]. In general, the power generated from the PV module is inversely proportional to the temperature of the PV panel, when the temperature is above the optimal range [4]. In the earlier days of the PV module, air and water were used as the coolant to maintain the temperature. To understand the impact of cooling achieved by the nanoparticles, several researchers are attempting to use it in the PV modules to improve their overall efficiency. The nanoparticles are added to the base coolant fluids like water, oil, and ethylene glycol to form the nanofluid. The major advantage of using nanofluids as a coolant is that the rheological and thermal properties can be effectively controlled [3]. The Al_2O_3 or aluminum trioxide is a well-known ceramic material that is being used in nanofluids owing to its thermal and chemical stability. The Al_2O_3 is available in different phases and each phase has its characteristics. Among the different phases, the alpha phase shows superior characteristics and are used widely in different application [5]. Many research works involved the usage of circular tubes or square tubes in different arrangements to study the effectiveness of the nanofluid in improving the performance of PV modules. To the authors' knowledge, not many experimental studies have been conducted using baffled tubes. In the present work, the PV module is constructed using soda glass, EVA, and PV cells. The constructed PV module is used with the Al_2O_3 nanofluid to evaluate its effectiveness while flowing through the tube with a square cross-section. The square tube has baffles at an angle of 30°.

Literature survey

The impact of CuO and Al_2O_3-based nanofluids is studied experimentally over the photovoltaic thermal (PVT) system efficiency and compared with that of water. All three fluids were employed to transfer the heat from the PVT system. The study showed that the usage of CuO nanofluid increased the electrical and thermal efficiency in comparison with the water by 0.07% and 21.30%, respectively. However, the Al_2O_3-based nanofluid improved the thermal efficiency by 15.14% and there was no significant improvement in the electrical efficiency [6]. The efficiency of the hybrid PVT-thermoelectric system is studied through an indoor experiment through different cooling mediums. The study is carried out using air, water, silicon dioxide nanofluid, and ferrous oxide nanofluid. The water is the base fluid for both the nanofluids. The impact of the cooling medium is studied based on the parameters of exergy and energy. From the analysis, it was observed that the nanofluid with silicon dioxide performed better than another cooling medium. In general, the usage of nanofluids improved the exergy efficiency, and the lowest power is generated from the hybrid PVT-thermoelectric system with air as the cooling medium [7]. The silver nanofluid is synthesized with water as a base fluid. The synthesized nanofluid is obtained through the wire explosion method and is tested for its uniformity and stability. The obtained result showed that the silver nanofluid improve the exergy and energy efficiency than that of water. The maximum overall efficiency for the PVT system is observed for nanofluid with 4% silver and the minimum efficiency is observed for the water. The efficiency of exergy is improved by 30% while using the nanofluid in comparison with that of water [8]. The Al_2O_3 nanofluid is used as the coolant experimentally to study its impact on the efficiency of the PVT system. The Al_2O_3 nanofluids are prepared with water as the base fluid at five different concentrations 0.05%, 0.075%, 0.1%, 0.2%, and 0.3%. The nanofluids are pumped at three different velocities 0.6 Lpm, 1.2 Lpm, and 0.9 Lpm. The experimental result showed that the overall efficiency of the PVT is improved by 74% at 0.1% volumetric concentration of Al_2O_3. At the optimum flow rate of 1.2 Lpm of nanofluid, the efficiency is increased by about 40.9% in comparison with that of water. From the study, it is observed that an increase in the flow rate of nanofluid increases the efficiency of the PVT system [9]. The effectiveness of Al_2O_3 and TiO_2 nanofluids as a coolant in the PV system is studied at various concentrations as 0.10%, 0.05%, and 0.01%. The flow rate for the aforementioned nanofluids was maintained at 500-5000 mL per minute. In comparison with pure water, the temperature of the PV cell is lower when using the nanofluids. Among the two nanofluids, the Al_2O_3-based nanofluid improved the efficiency of the PV cell [10]. The silicon carbide-based nanofluid is used as the coolant to improve the effectiveness of the PVT panel. The nanofluids are synthesized with the volumetric concentration of 0.5% and 0.1% and are used at the flow rates of 2 Lpm, 0.5 Lpm, and 1 Lpm. The maximum overall efficiency and electrical efficiency is about 92.43% and 33.27% more than the base water at the concentration of 0.5 wt.% under 2 Lpm flow rate. The experiment showed the effectiveness of using silicon carbide as a nanofluid in cooling the PVT panels [11]. The numerical study is carried out to examine the effectiveness of using Al_2O_3 and Ti nanofluid in enhancing PVT systems. The mathematical model of the PVT systems is developed and analyzed on parameters of electrical power, efficiency, and PV thermal. The analysis showed that the maximum electrical and thermal power obtained at 0.03 kg/s of Al_2O_3 nanofluid is about 12.11% more than the same fluid at 0.005 kg/s. From the analysis, it was observed that Al_2O_3-based nanofluid is better than TiO_2 nanofluid as a coolant for the modeled PVT system [12]. A similar result was also observed in the study conducted on the PVT collector [13]. The impact of the pumping power of nanofluid on the performance of the PVT system is studied with different designs. The study used carbon nanotubes-based nanofluids at 1% volumetric concentration with the flow rates increasing from 25-440 Lph. The optimum flow rate for the carbon nanotube is observed to be 100 Lph above which the performance of the PVT system is decreased [14]. The nanofluid of water-magnetite is used as the coolant in the PVT system with a tube collector to investigate its effectiveness. The study showed that a 2% concentration of magnetite with an 80 kg per hours flow rate provided better performance. The maximum improvement of 29.5%, 31.5%, and 27.5% in the generation of electrical power is achieved over 3-star rifled, 6-star rifled, and base fluid PVT systems, respectively, in comparison with PVT systems without cooling [15]. Two different nanofluids with Al_2O_3, CuO, and water are used in the PVT system to improve its performance. The study observed that the usage of nanofluids improved the system efficiency in comparison with conventional heat transfer [16].

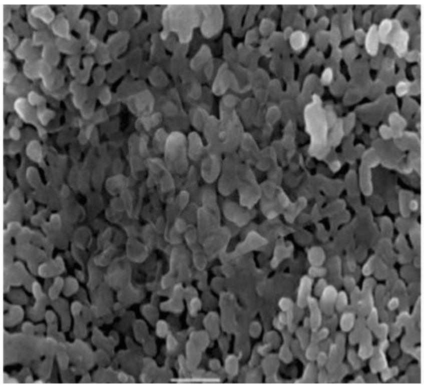

Figure 1. The SEM image of Al_2O_3

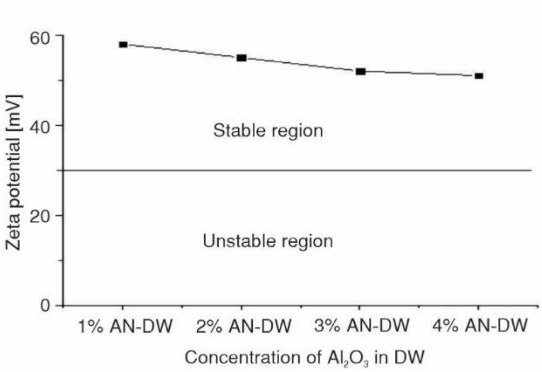

Figure 2. Zeta potential for different nanofluid concentrations

Preparation of alumina nanofluid

The alpha-phase Al_2O_3 nanoparticle is obtained with a particle size of 20 nm. The SEM image of the Al_2O_3 nanoparticle is given in fig. 1. The obtained Al_2O_3 is dispersed into 15 L of deionized water (DW) at the weight percentages of 1%, 2%, 3%, and 4%. The sodium dodecyl sulfate stabilizer is also added to the nanofluid mixture to avoid the formation of amino acids. The ultrasonic probe of the sonicator apparatus is employed to disperse the nanoparticles uniformly within the DW. The sonicator generally operates at a higher frequency and it causes overheating which may result in the evaporation of the nanofluid and hence covered with the ice cubes. The sonicator was operated for 1 hour for each proportion of nanofluids to get the proper dispersion. The obtained nanofluids are stable for 16 days without any sedimentation. The Zeta potential test was performed by Zetasizer to ensure the stability of the Al_2O_3 nanofluid and is shown in fig. 2. From fig. 2. it was clear that all the Al_2O_3 nanofluids used for this study are stable as all the values are more than +30 mV. With the increase in concentration, the zeta potential value decreases [17]. The thermal conductivities of DW and Al_2O_3 nanofluid are given in fig. 3.

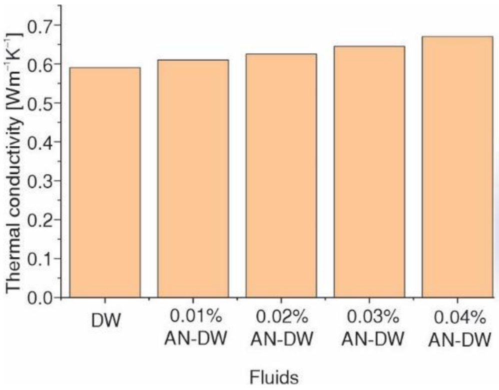

Figure 3. Thermal conductivity *vs.* volume fraction

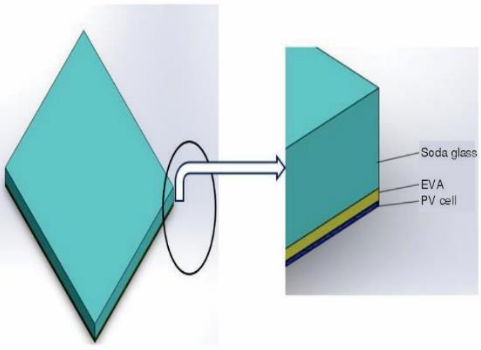

Figure 4. Description of solar module

Experimental set-up

The experimental set-up for the proposed research work is the PV module that was constructed using the soda glass, EVA, and the PV cell. The property of each material is given in tab. 1 and its arrangement is shown in fig. 4. From the entrance to the exit of the PV solar cell fluid flows. Temperature is lowered throughout this process, which is used to gauge how effective PV solar cells are. An illustration of the process flow is shown in figs. 5(a) and 5(b). This work looked at a PV solar unit section with a dimension of 66 cm × 54 cm × 0.42 cm as well as –0.4% per K as temperature as a factor. Irrespective of the reality the architecture of a 1.5 cm × 3.0 cm temperature absorber panel with the indirect flow conforms to the investigation. The Al_2O_3 nanofluid is synthesized using the DW at different volume fractions from 0.01% to 0.04%. Additionally, the flow rate of the Al_2O_3 nanofluid is varied from 10 Lph to 60 Lph. The nanofluid is made to flow through the baffled square tube with a cross-section area of 12 mm^2 × 12 mm^2 and it has the baffle at an angle of 30°.

The area of study is at Thanjavur region in Tamil Nadu in the southern part of India which is located at the latitude of 31 160 ^{o}N, and longitude of 32 180 ^{o}E. The summer period in this area lasts for roughly six months, from March to August, with mean temperatures ranging between 36 °C and 32 °C. The experiment, using the system, ran from May to July 2022.

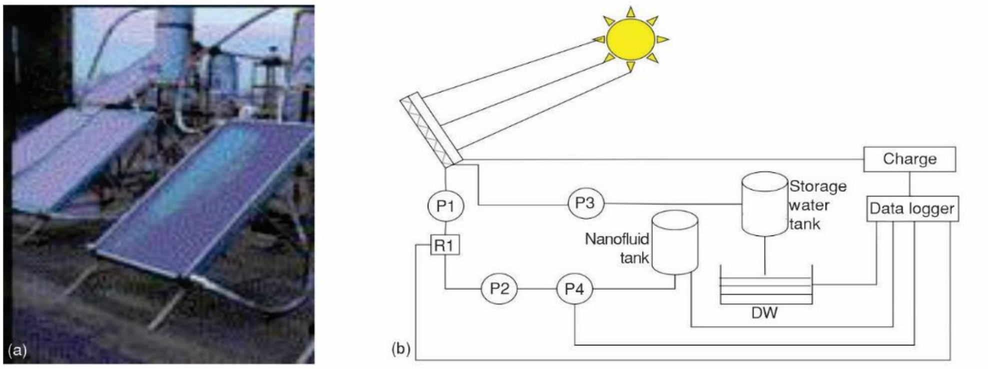

Figure 5. Image of solar PV unit (a) and representation chart of investigational system (b)

Table 1. Description of the surfaces on solar photovoltaic panels

Surfaces	Density [Kgm^{-3}]	Specific heat retention [$Jkg^{-1}K^{-1}$]	Resistivity related to heat [$Wm^{-1}K^{-1}$]	Depth [cm]
Soda glass	2530	810	0.76	0.300
EVA	960	2090	0.31	0.040
PV panel	2280	684	136	0.017

Calculations

The performance of the Al_2O_3 nanofluid used in the PV module is evaluated on overall efficiency, thermal efficiency, and electrical efficiency. The overall efficiency of the PV module is equal to the ratio of both the thermal and electrical output to that of incident solar radiation per unit area of the PV cell and it is denoted as η_o. The overall efficiency of the PV module is given as:

$$\eta_o = \frac{E_t + E_e}{E_i} \tag{1}$$

where E_t and E_e are the rates of thermal and electrical output power per unit area of the collector and the PV panel, respectively.

The thermal efficiency for the PV module is represented as η_t calculated using:

$$\eta_t = \frac{C_p \Delta T \dot{m}}{A_a T_s} \tag{2}$$

where $\Delta T = (T_o - T_i)$, T_o and T_i are the outlet and inlet temperature of fluid, $\dot{m}$, and C_p are the mass-flow rate and specific heat capacity of nanofluid, respectively, A_a is the area of the collector, and T_s is the total solar radiation.

The electrical efficiency for the PV module is represented as η_e calculated using:

$$\eta_e = \frac{E_e}{E_i} \tag{3}$$

where E_i is the input electrical power for the PV module.

Result and discussion

The performance of the Al_2O_3 nanofluid on cooling the PV module is evaluated for the parameters mentioned in the earlier section. The overall efficiency of the PV module is calculated and it is given in fig. 6. The overall efficiency of the PV module is higher in comparison with the base fluid to the flow rate of 40 Lph and above it, the efficiency decreased. The major reason is that as the flow exceeds the flow rate of 40 Lph, there is a variation in the flow characteristics which leads to lower heat absorption [18]. The maximum overall efficiency is observed at the volume fraction of 0.04%. In general, with the increase in volume fraction, the viscosity increases and it results in pressure loss which affects the overall efficiency of the PV module [19]. However, 0.04% volume fraction showed better performance with low viscosity as its concentration level is less in DW. The overall efficiency of the Al_2O_3 nanofluid with a flow rate of 40 Lph is 75% more than that of the base fluid.

The temperature of the PV module is one of the most important parameters that affect the performance of the PV module. Hence, the temperature profile for the PV module using Al_2O_3 nanofluid at different concentrations is observed. The temperature profile is observed for various concentrations of nanofluid with an optimum flow rate of 40 Lph. The PV module showed a maximum temperature of 78 °C when DW was used as the coolant at the time of 13:00. For the same PV module at the same period the temperature is observed to be 42 °C which is approximately 46.15% less. The temperature profile for the PV module is given in fig. 7.

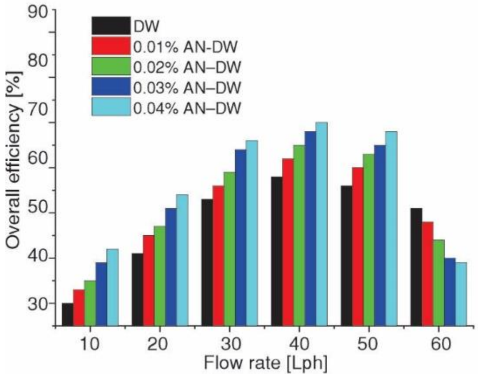

Figure 6. The overall efficiency of PV module

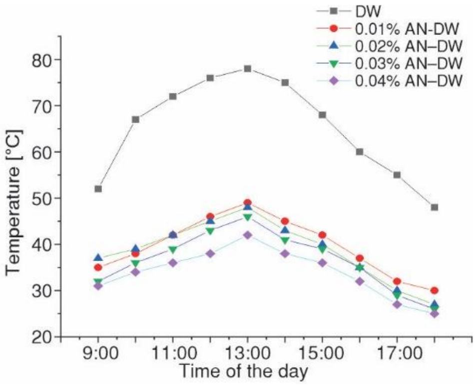

Figure 7. Temperature profile of PV module

The impact of Al_2O_3 nanofluid on the electrical efficiency of the PV module is observed and the values are plotted as shown in fig. 8. The evaluation is carried out with the optimum flow rate for different concentrations of nanofluids. Similar to the overall efficiency, the electrical efficiency is also higher for the PV panel provided with 0.04% Al_2O_3 nanofluid. The maximum electrical efficiency is observed to be 20% during 13.00 hours in comparison with 11% while using DW. The impact of Al_2O_3 nanofluid over the thermal efficiency of the PV module is observed and the values are plotted as shown in fig. 9. Similar to electrical efficiency, the thermal efficiency is evaluated with the optimum flow rate of 40 Lph at different concentrations of nanofluids. Similar to the overall efficiency, the thermal efficiency is also higher for the PV panel provided with 0.04% Al_2O_3 nanofluid. The maximum electrical efficiency is observed to be 32% during 13.00 hours in comparison with 25% while using DW.

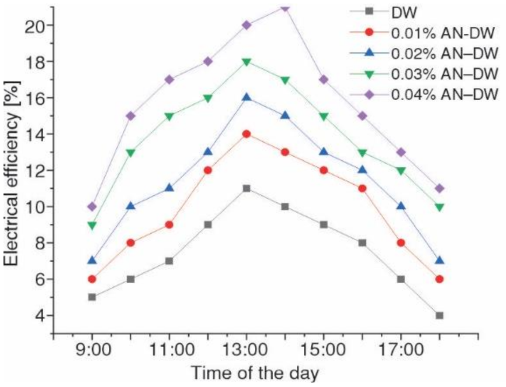

Figure 8. Electrical efficiency of PV module

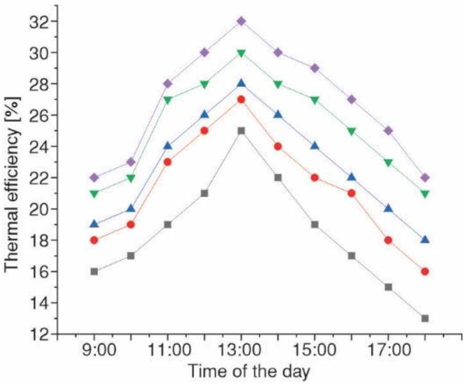

Figure 9. Thermal efficiency of PV module

Conclusions

The present work analyzed the effectiveness of the Al_2O_3-based nanofluid to improve the efficiency of the PV module. The α-Al_2O_3 nanoparticle with the size of 20 nm is obtained and its nanofluid is synthesized using the DW. The Al_2O_3 is added at four different weight concentrations at 0.01%, 0.02%, 0.03%, and 0.04% into the DW to obtain the nanofluid for the PV module. The Al_2O_3 nanofluid is used as a coolant and is pumped at a different flow rate ranging from 10 Lph to 60 Lph using the baffled tube with a square cross-section. The readings are taken throughout the day to determine the overall efficiency of the PV module along with its thermal and electrical efficiency. From the experimentation, the following inferences are observed.

- The usage of nanoparticles along with the base DW in the form of nanofluid decreased the temperature rise in PV modules.
- The optimum flow rate for the Al_2O_3 nanofluid is observed to be 40 Lph and above which the performance of the PV module decreases.
- The optimum concentration for the Al_2O_3 nanofluid is observed to be 0.04% and above which the performance of the PV module decreases.
- The maximum temperature on the PV module is observed to be at 1.00 p. m. for all the fluids employed in the study.
- The overall efficiency of the PV module is increased by 75% while using Al_2O_3 nanofluid as a coolant in comparison with the base DW at the optimum operating level.
- The electrical efficiency of the PV module is increased by 81.81% while using Al_2O_3 nanofluid as a coolant in comparison with the base DW at the optimum operating level.
- The thermal efficiency of the PV module is increased by 28% while using Al_2O_3 nanofluid as a coolant in comparison with the base DW at the optimum operating level.

The future scope involves the performance analysis of Al_2O_3 nanofluid as a coolant in the square tube with different baffle angles. Additionally, hybrid nanofluids can be developed with an Al_2O_3 DW mixture to analyze the performance of the PV module.

Nomenclature

A_a – area of the collector, [m^2]
C_p – specific heat capacity, [kJkg^{-1}K^{-1}]
E_t – thermal power output, [W]
E_i, E_e – electrical power input and power output, [W]
$\dot{m}$ – mass-flow rate, [kgs^{-1}]

T_o, T_i – outlet and inlet temperature of the fluid, [K]
T_s – total solar radiation, [Wm^{-2}]
ΔT – temperature difference, [K]

Greek symbols

η_o – overall efficiency, [%]
η_e – electrical efficiency, [%]
η_t – thermal efficiency, [%]

Acronyms

AN – alumina nanofluid (fig. 2)
DW – deionized water
EVA – ethylene vinyl acetate
PVT – photovoltaic thermal

References

[1] Kumar, R., *et al.*, Performance Enhancement of Photovoltaic Modules by Nanofluid Cooling: A Comprehensive Review, *International Journal of Energy Research, 44* (2020), 8, pp. 6149-6169
[2] Gao, M., *et al.*, Solar Absorber Material and System Designs for Photothermal Water Vaporization Towards Clean Water and Energy Production, *Energy & Environmental Science, 12*, (2019), 3, pp. 841-864
[3] Boldoo, T., *et al.*, Review of the Photothermal Energy Conversion Performance of Nanofluids, Their Applications, and Recent Advances, *Energies, 13* (2020), 21, 5748
[4] Dubey, S., *et al.*, Temperature Dependent Photovoltaic (PV) Efficiency and Its Effect on PV Production in the World – A Review, *Energy Procedia, 33* (2013), 3, pp. 311-321
[5] Singh, M., *et al.*, Experimental Study on Thermal Conductivity and Viscosity of Al_2O_3-Nanotransformer Oil, *Int. J. on Theoretical and Applied Research in Mech. Eng. (IJTARME) 2* (2013), 3, pp. 2319-3182
[6] Fakouriyan, S., *et al.*, Experimental Analysis of a Cooling System Effect on Photovoltaic Panels' Efficiency and Its Preheating Water Production, *Renewable Energy, 134* (2019), Apr., pp. 1362-1368
[7] Lee, J. H., *et al.*, Efficiency Improvement of a Photovoltaic Thermal (PVT) System Using Nanofluids, *Energies, 12* (2019), 16, 3063
[8] Soltani, S., *et al.*, Exergetic and Environmental Assessment of a Photovoltaic Thermal-Thermoelectric System Using Nanofluids: Indoor Experimental Tests, *Ene. Conversion and Manag.*, 218 (2020), 112907
[9] Aberoumand, S., *et al.*, Energy and Exergy Analysis of a Photovoltaic Thermal (PV/T) System Using Nanofluids: An Experimental Study, *Solar Energy*, *165* (2018), May, pp. 167-177
[10] Abdallah, S. R., *et al.*, Experimental Investigation on the Effect of Using Nano Fluid (Al2O3-Water) on the Performance of PV/T System, *Thermal Science and Engineering Progress*, 7 (2018), Sept., pp. 1-7
[11] Ebaid, M. S. Y., *et al.*, Experimental Investigation of Cooling Photovoltaic (PV) Panels Using (Tio2) Nanofluid in Water-Polyethylene Glycol Mixture and (Al_2O_3) Nanofluid in Water-Cetyltrimethylammonium Bromide Mixture, *Energy Conversion and Management*, *155* (2018), Jan., pp. 324-343
[12] Abbood, M. H., *et al.*, Improving the Electrical Efficiency of a Photovoltaic/Thermal Panel by using SiC/Water Nanofluid as Coolant, *IOP Con. Series: Materials Science and Eng.*, 671 (2020), 1, 012143
[13] Jia, Y., *et al.*, Numerical Analysis of Photovoltaic-Thermal Collector using Nanofluid as a Coolant, *Solar Energy*, *196* (2020), Jan., pp. 625-636
[14] Rahmanian, S., *et al.*, Effects of Pump Power on Performance Analysis of Photovoltaic Thermal System using CNT Nanofluid, *Solar Energy, 201* (2020), May, pp. 787-797
[15] Shahsavad, A., *et al.*, Experimental Investigation of the Usability of the Rifled Serpentine Tube to Improve Energy and Exergy Performances of a Nanofluid-Based Photovoltaic/Thermal System, *Renewable Energy, 170* (2021), June, pp. 410-425
[16] Mahmood, H. A. A., *et al.*, Performance Evaluation of a Photovoltaic Thermal (PVT) System using Nanofluids, *Energies*, *14* (2021), 2, 301
[17] Syarif, D. G., Characteristics of Ethylene Glycol-Al_2O_3 Nanofluids Prepared by Utilizing Al_2O_3 Nanoparticles Synthesized from Local Bauxite, *Journal of Physics: Conference Series*, *776* (2016), 1, 012042
[18] Sheikholeslami, M., *et al.*, Recent Progress on Flat Plate Solar Collectors and Photovoltaic Systems in the Presence of Nanofluid: A Review, *Journal of Cleaner Production*, *293* (2021), 126119
[19] Hissouf, M., *et al.*, Performance of a Photovoltaic-Thermal Solar Collector using Two Types of Working Fluids at Different Fluid Channels Geometry, *Renewable Energy, 162* (2020), Dec., pp. 1723-1734

Paper submitted: August 29, 2023
Paper revised: October 16, 2023
Paper accepted: November 3, 2023