COMPARATIVE ANALYSIS OF CuO-BASED SPIRAL FLOW PHOTOVOLTAIC SHEET AND TUBE THERMAL SYSTEM

by

***Manish DESHMUKH*[a], *Jitendra SATPUTE*[b], *Nikhil PURWANT*[c], *Dheeraj DESHMUKH*[d], and *Sandip CHAVHAN*[e*]**

[a] Department of Mechanical Engineering, AISSMS College of Engineering, Pune, Maharashtra, India
[b] Department of Mechanical Engineering, Suman Ramesh Tulsiani Technical Campus Pune, Maharashtra, India
[c] Department of Mechanical Engineering, JSPM's Rajarshi Shahu College of Engineering, Tathawade, Pune, Maharashtra, India
[d] Department of Mechanical Engineering, G. H. Raisoni College of Engineering, Nagpur, Maharashtra, India
[e] Department of Mechanical Engineering, G. H. Raisoni Institute of Engineering and Technology, Pune, Maharashtra, India

Original scientific paper
https://doi.org/10.2298/TSCI201112197D

The current work investigates experimental characteristics of the PVT system integrated with CuO-water spiral flow heat exchanger and compared with non-cooled PV module. The work describes detailed procedure of nanoparticles preparation, SEM characterizations, and heat extraction characteristics of nanofluid in PVT application. The heat exchanger was pasted at the back of polycrystalline PV module to form PVT system to examine cooling ability, power generation, thermal-electrical yield and overall efficiency at a different volume concentration of CuO nanoparticles at steady mass-flow rate of 0.08 kg/s. From the experiments, it was concluded that the CuO-water nanofluids assisted to lessen surface temperature of PV module by extracting heat that enhanced electrical efficiency by an average of 3.53%. It was also seen that electrical and thermal performance was improved at higher volume concentration and overall efficiency of 30.77% and 36.59% were obtained at 0.01% and 0.03% of volume concentration.

Key words: *solar energy, nanofluid, CuO-water, volume concentration, electrical-thermal performance*

Introduction

The modern energy sector prefers renewable sources over conventional fuels to fulfil energy demand that can also reduce widespread climate threats and global warming. From 1990 to 2017, highest average annual growth in the renewable sector of 37% was seen for solar PV technology followed by 26% wind power according to International Energy Agency (2019). The solar PV technology is clean source of energy that converts solar radiation in to electricity without moving parts *via* PV effect. In the PV effect, the photons from sunlight fall

* Corresponding author, e-mail: sandip4284@gmail.com

on surface of semiconductor material and excited electrons generate potential difference gives rise to electrical power. The main factor limiting use of PV technology is reduction in magnitude of power generation at elevated PV surface temperature. However significant development in cooling technology made possible to enhance performance of PV module. The cooling fluid not only extracts heat from PV module but also extracted heat can be utilized for variety of energy applications. The combine PV system along with heat exchanger to offer cooling is known as PVT system [1].

The recent advancement in cooling technology was studied by Satpute, *et al.* [2], where they discussed water, air, PCM, refrigerant, nanofluid and combination of two or more fluids for PV cooling. Many researchers have used water and air as heat transfer medium to offer cooling and recuperate waste heat due to is ample availability, chemical stability, and low-cost characteristics. Ordoumpozanis, *et al.,* [3], Dubey and Tiwari [4], Duperat *et al.* [5], Dubey *et al.* [6], Haurant *et al.* [7] performed parametric study with water as a working fluid to provide cooling and recover waste heat with various configuration of thermal absorber. Similarly, Teo *et al.* [8], Bambrook *et al.* [9], Tonui and Tripanagnostopoulos [10] studied air as a cooling medium for PV module. These conventional cooling fluids have the inherent constraint of lower thermal conductivity and heat transfer coefficient. In 21st century, the researchers were tuned towards up-gradation of conventional and well-accepted cooling mediums with nanofluid (NF). The NF is the composed blend of nanoparticles (NP) suspended in a base fluid with a range of concentrations by volume or weight. Initially, Taniguchi [11] proposed *nanotechnology* as technology of manometer size material. The properly disperse NP offered enhanced micro convective heat transfer, stability, surface to volume ratio.

Michael and Iniyan [12] proposed PVT collector with copper sheet thermal absorber using CuO-water NF. The CuO-water based PVT offered thermal efficiency up to 45.76% whereas electrical efficiency was lowered compared to water-PVT. The work also suggests emphasizing on effective thermal absorber design to improve overall efficiency of PVT system. Sardarabadi *et al.* [13] proposed SiO_2-water NF at 1% and 3% weight concentrations. Total exergy of 24.31% was achieved with silica-water NF at 3% weight concentration whereas it was 22.61% and 19.36% at 1 wt.% concentration and water-PVT, respectively. Ghadiri *et al.* [14] did similar experimental work with Fe_3O_4-water in PVT system. Since the ferrofluid changes its thermos-physical properties during magnetic field, study was performed under constant and alternating magnetic field at 1% and 3% weight concentration.

The study concluded that alternating magnetic field of 50 Hz with higher concentration enhances the PVT performance. Variety of NF such as nanotube-H_2O, graphene-H_2O, CuO-H_2O, Al_2O_3-H_2O, TiO_2-H_2O, and SiO_2-H_2O were proposed by Verma *et al.* [15] for optimum concentration, mass-flow rate, energy efficiency, and entropy generation. They found multiwall nanotube-water as better NF among all as at 0.75% particle and flow rate of 0.025 kg/s. Energy efficiency of 23.47% and entropy generation drop of 65.55% was seen. Gangadevi *et al.* [16] analyzed the thermos-physical property of ZnO-water NF and proposed it as a heat transport medium in the PVT application. In the work, experiments were conducted at 40 Lph and concentration of 0.05, 0.1, and 0.2%, respectively. The PVT efficiency was observed up to 93% at an upper volume concentration of 0.2%.

Hussein *et al.* [17] presented performance improvement using Zn-H_2O nanofluid in PV system under Iraqi weather conditions. The actively cooled pipe heat exchanger was designed and heat transport was investigated at five concentration ratios of 0.1, 0.2, 0.3, 0.4, and 0.5%. The nanometric size of NP and heat transfer characteristics was investigated by Davarnejad *et al.* [18]. They proposed average 20 nm and 50 nm NP size and performance results were compared with water. It was seen that nanofluid with 50 nm nanometric size demonstrated better average heat transport characteristics and Nusselt number due to higher surface area at increasing flow rate.

An indoor experimental work with multiwall carbon nanotube-water NF was performed by Narsin *et al.* [19] for PVT application and 87.65% of overall efficiency was recorded and numerically validated. The performance augmentation of PVT system with NF cooling was endorsed by Fudholi *et al.* [20]. The TiO_2-water NF with 0.5 wt.% and 1 wt.% at varying solar concentration was studied under uniform mass-flow rate. The PVT efficiency was raised to 89% with 1 wt.% NF whereas it was limited to 76% with water cooling. Gangadevi *et al.* [21] experimentally examined Al_2O_3-water NF for PVT application in Chennai India to investigate overall performance. The spiral flow thermal absorber was proposed and Al_2O_3-water has circulated at mass flow rate of 40 Lph with 1 wt.% and 2 wt.% concentration. The result endorsed a higher concentration of NF for better performance as enhanced PVT efficiency of 58% was obtained during experimentation.

During the experimentation Garg and Agarwal [22] was discovered that for $Ac = 2.0$ m^2, $P = 1.0$, $Mw = 100$ kg, and $m = 0.03$ kg/s, approximately 340.9 Wh per day of directly converted electrical energy was available. A typical domestic solar water heater of around 2 m^2 produces enough electrical energy (after accounting for losses in storing, *etc.*, as well as the effort required primarily by the pump) to power two 20 W tube lights for only 5 hours. Yildirim *et al.* [23] concluded that most other PV devices have lower seasonal self-sufficiency values than mono-Si. Even among the numerous benefits PV areas determined based on annual load profile, CdTe has the best seasonal efficiency of 18% self-sufficiency in winter and 59% in summer. Throughout the FIT case, summer self-sufficiency with CdTe innovation appears to be 79%. In 2013, Panti *et al.* [24] tested an efficiently oriented monocrystalline solar module of 60 Wp produced 62.9 kWh with electric power, a horizontal module 58.1 kWh, a vertical subsystem oriented towards its south 43.9 kWh, a vertical module focused towards to the east produced 25.7 kWh, as well as a vertical module oriented towards its west generated 22.9 kWh.

Nanofluid preparation and characterization

The analytic reagent grade copper (II), chloride ($CuCl_2$), and potassium hydroxide (KOH) from Merck India Ltd. were taken in the experiment work and CuO was synthesized using 500 ml of copper chloride solution and alkali, fig. 1. An approach reported by Tran and Nguyen [25] was adopted for NP preparation. The equimolar ratio of copper (II) chloride 0.1 M and potassium hydroxide 0.5 M pallets were separately dissolved in the deionized water. At normal pressure conditions, continuous stirring was maintained during dropwise accumulation of potassium hydroxide solution to copper (II) chloride hydrate to ensure uniform mixing. Then the mixture was heated to 70 ºC for an hour and resulted black colored copper hydroxide solution was filtered twice using filter paper until it completely solidifies.

The black-colored solidified copper hydroxide was annealed at temperature of 200 ºC in the electric muffle furnace for three hours to obtain crystalline structure. Finally, the sample was ground into fine powder form to obtain court-NP and characterization were performed.

From the micrograph of CuO; one can observe the formation of grain boundaries with flake like morphology, fig. 2. Most of the flakes are irregular in shape with broad size distribution (~120–600 nm) due to particle aggregation with crystal growth at the time of synthesis. The congregate morphology plays an important role in crystal growth and also conserving energy and densification is driven as a counterpart of NF.

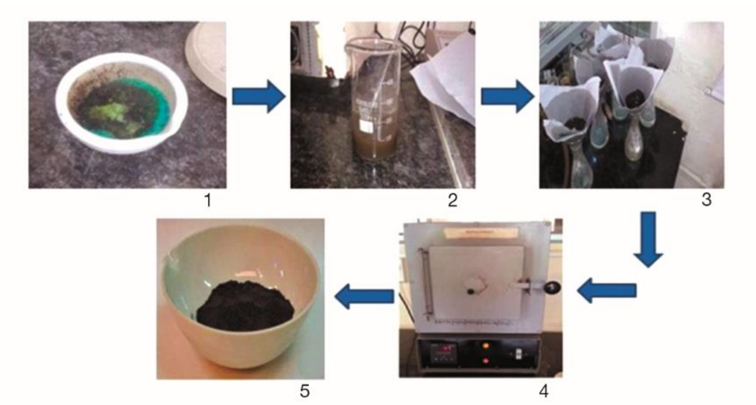

Figure 1. (a) Mixture of KOH and $CuCl_2$, (b) mixture + water, (c) precipitation, (d) furnace heating, and (e) CuO NP

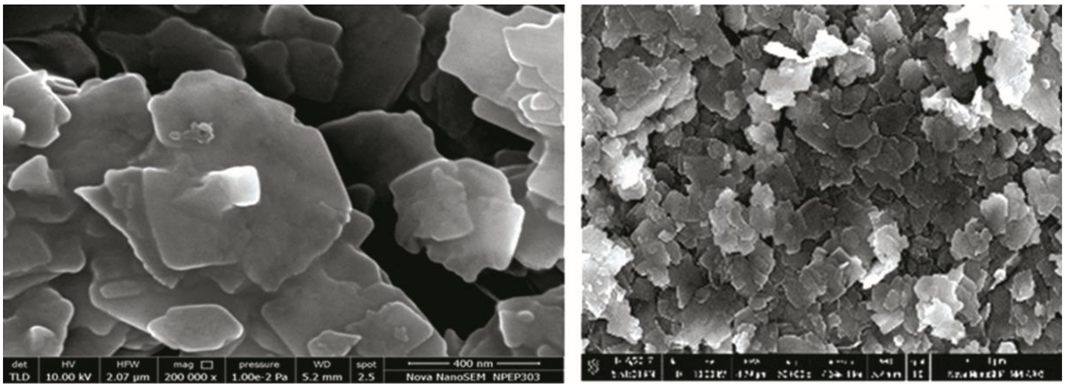

Figure 2. Micrograph of CuO

Experimental set-up

The set-up was manufactured, assembled and installed at the terrace of institute to ensure maximum radiation will fall on PVT system. The two identical PV modules one with sheet and tube heat exchanger (PVT system) and another without heat exchanger (non-cooled PV module) were placed on same structure and exposed to ambient condition for experimental work, fig. 3. The copper material with high thermal conductivity (385 W/mK) was used to manufacture round spiral heat exchanger and soldered to copper sheet, fig. 4. The copper sheet was pasted to the backside of PV panel and wooden blocks were used to make sure proper surface contact. The both end of the tube are connected with common tank of capacity 50 L and centrifugal pump of 0.5 kW was used to circulate the CuO-water NF. The *K*-type thermocouples are incorporated for temperature measurement in experimental set-up.

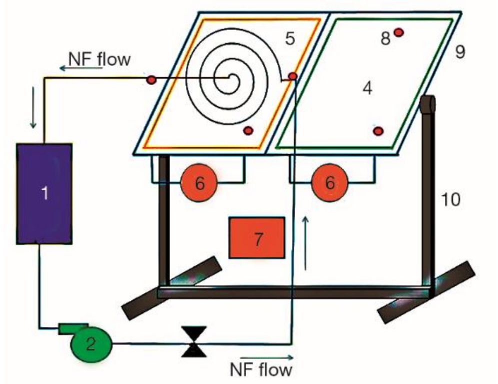

Figure 3. Experimental set-up; *1 – NF tank, 2 – NF circulation pump, 3 – flow control valve, 4 – PV module, 5 – PVT system, 7 – temperature display unit, 8 – thermocouple, 9 – PV, PVT holder stand, 10 – supporting structure*

Figure 4. Design of heat exchanger

Performance evaluation

The incident radiation on PVT system is main source of input to generate electrical and thermal energy. The various measuring instruments are used to record observations and discussed in methodology section. The measured quantities are used to analyze performance indicators as follows,

The PVT efficiency of CuO-water NF PVT (ηPVT) is function of electrical power, thermal power, incident radiation and PVT system area as per Garg [22]:

$$\eta_{\text{PVT}} = \frac{P_{\text{thermal}} + P_{\text{electrical}}}{P_{\text{incident}}}$$

The thermal power of CuO-water NF PVT is:

$$P_{\text{thermal}} = m_f C_p (T_{fi} - T_{fo})$$

Similarly, electrical output power is:

$$P_{\text{electrical}} = V_{\text{oc}} I_{\text{SC}} FF$$

Based on the evaluation, performance characteristics of thermal-electrical and overall efficiencies are evaluated:

$$\eta_{\text{thermal}} = \frac{P_{\text{thermal}}}{I_{\text{R}} A_{\text{TC}}}$$

$$\eta_{\text{electrical}} = \frac{P_{\text{electrical}}}{I_{\text{R}} A_{\text{PV}}}$$

$$\eta_{\text{PVT}} = \eta_{\text{thermal}} + \eta_{\text{electrical}}$$

While preparing NF, the weight of CuO for percent volume concentration was decided by vol.% concentration:

$$\phi = \left[\frac{\dfrac{W_{\text{CuO}}}{\rho_{\text{CuO}}}}{\dfrac{W_{\text{CuO}}}{\rho_{\text{CuO}}} + \dfrac{W_{bf}}{\rho_{bf}}} \right] 100, \qquad \phi = \left[\frac{\dfrac{W_{\text{CuO}}}{6300}}{\dfrac{W_{\text{CuO}}}{6300} + \dfrac{100}{1000}} \right] 100$$

where density of CuO is 6300 kg/m^3 and density of water is 1000 kg/m^3.

Result and discussion

The outdoor experimentations were performed with longitude 18.7611° N, latitude 73.5572° E and tilt angle of 20°, respectively, in summer season. The readings were recorded in the month of May on clear days from 10:00 a. m. to 15:30 p. m. after an interval of every half an hour and observation were used to evaluate performance characteristics.

Thermal characteristics

The variation in surface temperature of PV and PVT system during testing period was plotted in fig. 5. As discussed in introduction part, NF provide better convective heat transfer characteristics. It was seen that temperature of non-cooled PV module was continuously increasing up to 54.0 °C. When the CuO-water NF circulated through heat exchanger, surface temperature drop was observed. The temperature was reduced by 2.63% and 6.12% at 0.01 vol.% and 0.03 vol.%, respectively. The ambient temperature variations were recorded and followed similar profile as that of PV, PVT surface temperature.

Figure 6 justified use of higher concentration NF, as constant improved thermal efficiency was seen during test at 0.03 vol.%. The thermal performance is also function of incident radiation and heat exchanger design. With spiral flow heat exchanger, average thermal efficiency of 23.54% and 16.39% was recorded for 0.03 vol.% and 0.01 vol.%, respectively.

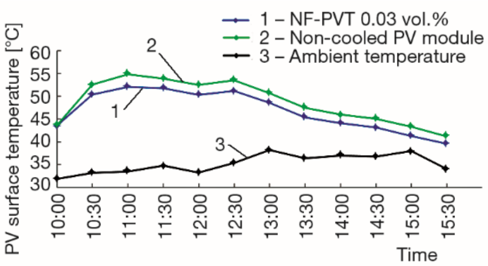

Figure 5. Effect on surface temperature of PV and PVT system with 0.01 vol.% and 0.03 vol.% CuO NF

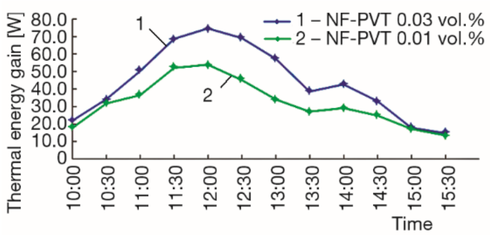

Figure 6. Effect on thermal efficiency of system with 0.01 vol.% and 0.03 vol.% CuO NF PVT

Electrical characteristics

The maximum electrical power obtained is product of voltage and current generated through PV and PVT system. As shown in fig. 7. In case of non-cooled PV module, power generation continuously turns down due to rise in radiation and surface temperature value. In the figure, better performance was observed with CuO-water NF circulation. It is the result of PV surface temperature stabilization achieved with NF. This drop of surface temperature amplified power generation capacity of PVT system. The electrical power of 37.35 W, 32.78 W, and 28.09 W generated through non cooled PV, 0.01 vol.% and 0.03 vol.% NF PVT.

The average electrical performance recorded for non-cooled PV module was 9.85% from fig. 8 whereas significant rise up to 12.88% examined with 0.03 vol.%. The highest electrical efficiency of 15.2% was observed in noon period at 0.03 vol.% concentrations and least electrical efficiency of 3.84% was recorded for non-cooled PV module in the afternoon period.

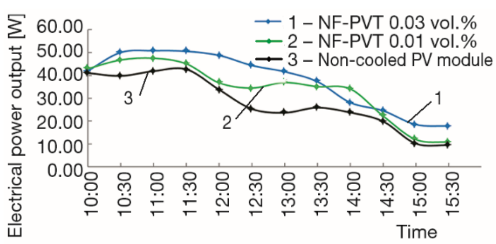

Figure 7. Variation of electrical power in case of non-cooled PV, 0.01 vol.% and 0.03 vol.% CuO-water NF PVT

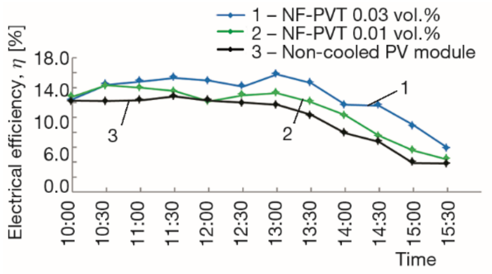

Figure 8. Effect on electrical efficiency with non-cooled PV, 0.01 vol.% and 0.03 vol.% CuO NF PVT

Overall characteristics

As seen in fig. 9, the PVT system has more overall efficiency that PV module due concurrent generation of two forms of energy. The overall efficiency of 36.59% and 30.77% were recorded for CuO-water NF-PVT with 0.03 vol.% and 0.01 vol.%. On the other hand, it was limited to 9.85% for non-cooled PV module. It is important to note that noticeable improvement in electrical and thermal performance was acknowledged with NF circulation.

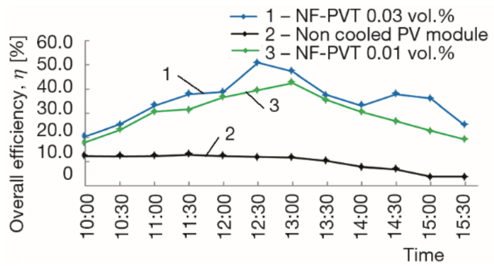

Figure 9. Variation in overall performance in case of non-cooled PV, 0.01 vol.% and 0.03 vol.% CuO NF PVT

Conclusion

A CuO-water NF PVT was designed and its outdoor performance was evaluated using 0.01% and 0.03% volume fraction at 0.08 kg/s. In the experimental analysis, it was seen that CuO-water NF-PVT system caused cooling of the PV module and resulted in improved electrical performance compared to PV module. The higher heat transport was seen at higher concentration of NP, which uplift electrical-thermal power gain. The thermal efficiency was increased from 16.39% at 0.01 vol.% to 23.54% at 0.03 vol.% whereas electrical efficiency was raised from 11.07% to 12.88% at constant flow rate of 0.08 kg/s. The overall efficiency of the CuO-water NF-PVT system is much significant than the PV module alone. Based on outdoor observations from lower concentration, electrical-thermal performance was discussed and can be further improved with higher concentration and flow rate.

Nomenclature

A_{PV} – area of PV module, [m^2]
A_{TC} – area of thermal collector, [m^2]
C_p – specific heat, [kJkg^{-1}K^{-1}]
FF – fill factor
I_{sc} – short circuit current, [Amp]
I_R – incident radiation, [Wm^{-2}]
m_f – mass CuO-water NF flow rate, [kgs^{-1}]
$P_{electriccal}$ – electrical power, [W]

$P_{thermal}$ – thermal power, [W]
$P_{incident}$ – incident power, [W]
T_{fi} – inlet temperature of CuO-water NF, [°C]
T_{fo} – outlet temperature of CuO-water NF, [°C]
V_{oc} – open circuit voltage, [v]
W_{CuO} – weight of CuO, [Kg]
W_{bf} – weight of base fluid, [Kg]

Greek symbols

$\eta_{thermal}$ – thermal efficiency
$\eta_{electrical}$ – electrical efficiency
η_{PVT} – photovoltaic thermal efficiency
ρ_{CuO} – density of CuO, [kgm^{-3}]
ρ_{bf} – density of base fluid
ϕ – percentage of volume concentration

References

[1] ***, IEA-International Energy Agency (2019), Renewables Information 2019, Paris, https://www.iea.org/reports/renewables-information-2019
[2] Satpute, J. B., Rajan, A. J., Recent Advancement in Cooling Technologies of Solar Photovoltaic (PV) System, *FME Transactions, 46* (2018), 4, pp. 575-584
[3] Ordoumpozanis, K., *et al.,* Energy and Thermal Modeling of Building Façade Integrated Photovoltaics, *Thermal Science, 22* (2018), Suppl. 3, pp. S921-S932
[4] Dubey, S., Tiwari, G., Thermal Modeling of a Combined System of Photovoltaic Thermal (PV/T) Solar Water Heater, *Solar Energy, 82* (2008), 7, pp. 602-612
[5] Dupeyrat, P., *et al.*, Efficient Single Glazed Flat Plate Photovoltaic-Thermal Hybrid Collector for Domestic Hot Water System, *Solar Energy, 85* (2011), 7, pp. 1457-1468
[6] Dubey, S., Tay, A. A., Experimental Study of the Performance of Two Different Types of Photovoltaic Thermal (PVT) Modules under Singapore Climatic Conditions, *Journal of Fundamentals of Renewable Energy and Applications, 2* (2012), ID R120313
[7] Haurant, P., *et al.,* A Numerical Model of a Solar Domestic Hot Water System Integrating Hybrid Photovoltaic/Thermal Collectors, *Energy Procedia, 78* (2015), Nov., pp. 1991-1997
[8] Teo, H., *et al.,* An Active Cooling System for Photovoltaic Modules, *Applied Energy, 90* (2012), 1, pp. 309-315
[9] Bambrook, S., Sproul, A., Maximising the Energy Output of a PVT Air System, *Solar Energy, 86* (2012), 6, pp. 1857-1871
[10] Tonui, J., Tripanagnostopoulos, Y., Air-Cooled PV/T Solar Collectors with Low Cost Performance Improvements, *Solar Energy, 81* (2007), 4, pp. 498-511
[11] Taniguchi, N., On the Basic Concept of 'Nano-Technology', *Proceedings,* Intl. Conf. Prod. Eng. Part II, Japan Society of Precision Engineering, Tokyo, 1974
[12] Michael, J. J., Iniyan, S., Performance Analysis of a Copper Sheet Laminated Photovoltaic Thermal Collector Using Copper Oxide – Water Nanofluid, *Solar Energy, 119* (2015), Sept., pp. 439-451
[13] Sardarabadi, M., *et al.*, Experimental Investigation of the Effects of Silica/Water Nanofluid on PV/T (Photovoltaic Thermal Units), *Energy, 66* (2014), Mar., pp. 264-272
[14] Ghadiri, M., *et al.*, Experimental Investigation of a PVT System Performance Using Nano Ferrofluids. *Energy Conversion and Management, 103* (2015), Oct., pp. 468-476
[15] Verma, S. K., *et al.,* Experimental Evaluation of Flat Plate Solar Collector Using Nanofluids, *Energy Conversion and Management, 134* (2017), Feb., pp. 103-115
[16] Gangadevi, R., *et al.,* Performance Analysis of Photovoltaic/Thermal Collector System Using ZnO/Water Nanofluid, *International Journal of Pure and Applied Mathematics, 118* (2018), 24, pp. 1-16
[17] Hussein, H. A., *et al.,* Improving the Hybrid Photovoltaic/Thermal System Performance Using Water-Cooling Technique and Zn-H_2O Nanofluid, *International Journal of Photoenergy, 2017* (2017), May, pp. 1-14
[18] Davarnejad, R., *et al.,* CFD Simulation of the Effect of Particle Size on the Nanofluids Convective Heat Transfer in the Developed Region in a Circular Tube, *SpringerPlus, 2* (2013), 192, pp. 1-6
[19] Nasrin, R., *et al.,* Water/MWCNT Nanofluid Based Cooling System of PVT: Experimental and Numerical Research, *Renewable Energy, 121* (2018), June, pp. 286-300
[20] Fudholi, A., *et al.,* TiO_2/Water-Based Photovoltaic Thermal (PVT) Collector: Novel Theoretical Approach, *Energy, 183* (2019), Sept., pp. 305-314
[21] Gangadevi, R., *et al.,* Experimental Investigations of Hybrid PV/Spiral Flow Thermal Collector System Performance Using Al_2O_3/Water Nanofluid, *IOP Conference Series: Materials Science and Engineering, 197* (2017), 012041
[22] Garg, H., Agarwal, R., Some Aspects of a PV/T Collector/Forced Circulation Flat Plate Solar Water Heater with Solar Cells, *Energy Conversion and Management, 36* (1994), 2, pp. 87-99

[23] Yildirim, E., Aktacir, M. A., Optimization of Photovoltaic System and Technology in view of a Load Profile: Case of Public Building in Turkey, *Thermal Science, 23* (2019), 6, pp. 3567-3577
[24] Pantić, L. S., *et al.*, Electrical Energy Generation with Differently Oriented Photovoltaic Modules as Facade Elements, *Thermal Science, 20*, (2016), 4, pp. 1377-1386
[25] Tran, T. H., Nguyen, V. T., Copper Oxide Nanomaterials Prepared by Solution Methods, Some Properties, and Potential Applications: A Brief Review, *International Scholarly Research Notices, 2014* (2014), ID 856592

Paper submitted: November 12, 2020
Paper revised: April 10, 2021
Paper accepted: April 12, 2021