A review: The effect of different nanofluids on various performance parameters of flat plate solar water heater

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Abstract- Solar energy-based techniques are the best techniques that converts the solar radiations in to useful form of energy like mechanical, thermal, chemical and electrical energies. This review article emphasizes on the solar energy-based technique that is flat plate solar water heater (FPSWH). Water has been used in FPSWHs for a long time, but it has less thermal conductivity, so there was a need of fluids, having high thermal conductivity. After several researches nanofluids were found, which have higher heat transfer capacity (thermal conductivity) than any base fluid like water, due to high thermal conductivity, system efficiency increases. This is the reason that now a days nanofluids are used in FPSWHs instead of base fluid (water). This study based on the previous experimental and theoretical analysis which have been done on nanofluids in FPSWHs. This study shows that with the increment in mass flow rate difference between inlet fluid temperature and outlet fluid temperature increases. With the use of CuO-water nanofluid efficiency of FPSC improves 5% as compare with water at same working conditions. Exergetic efficiency for CuO hybrid nanofluid was 70.63% and for MgO hybrid nanofluid was 71.54%, which indicates that the use of MgO hybrid nanofluid is more efficient than Hybrid CuO nanofluid. When wavy and spiral pipes are used in collector to change the direction of flow, coefficient of heat transfer and the value of Nusselt number are increased.

Key Words— Flat plate solar water heater, System efficiency, Base fluids, Nanofluids, Surfactants.

I. INTRODUCTION

The energy consumption increased in the world due to day by day changes in human lifestyle and development of new technologies. We have limited quantity of conventional sources to produce energy and these conventional sources also adversely affect the environment and world's economy. So there is a need to use sources which are environment friendly and abundantly available. To meet the need renewable energy sources are the best option. Wind energy, solar energy, hydropower, tidal energy etc. are the examples of renewable energies. Among these, solar energy distributed widely throughout the world. The utility of solar energy is increasing continuously in the field of energy generation [1].

Solar energy is converted into several kinds of energy like chemical, thermal, electrical and mechanical. The solar collector works as a heat exchanger, which converts the incident solar radiation comes from sun into thermal energy in solar thermal related applications by solar collector and electrical energy for photovoltaic related applications by photovoltaic cells. Solar collectors are mainly of two type's concentrator and nonconcentrator. Nonconcentrator is also known as FPSC (flat plate solar collector). FPSC absorbs solar radiation coming from sun and transforms it into thermal energy and transmits this thermal energy to the fluid passing in the collector to heat up the household water. FPSC have both in industrial and domestic applications. Conventional FPSC has low thermal efficiency due to low heat transfer coefficient between solar collector (absorber) and fluid passing through it. In recent trends to enhance the collector's performance, many other heat transfer materials are used, nanofluid is the one among them [2]. Nanofluid contains nanoparticles (very small sized particles <100 nm). These nanoparticles make a colloidal solution with base fluid. These nanoparticles are suspended in the water or any other base fluid [3].

Several studies have been conducted to analyze the effects of nanofluids on the performance parameters of FPSC. Yijie Tong et al. (2020) analyzed the effects of several nanofluids on the system performance characteristics of FPSC. The System performance increases when nanofluids are used and under several working conditions sensitivity of performance is lower than in the case of water or any other base fluid. The highest system efficiency has been achieved when MWCNT was used as nanofluid in FPSC [4]. M Faizal et al.(2013) investigated that the utilization of nanofluids in FPSC, can achieve the same required output with smaller size collector as achieved with water based bigger size collector. It had been evaluated that with the use of Al_2O_3, TiO_2, SiO_2, and CuO, someone can save 8618, 8857, 8625 and 10239 kg respectively for 100 units of FPSC. If nanofluids are used in solar collector, it can also reduce cost of environmental damage [5]. Erdogan Arikan et al. (2018) investigated the effect of nanofluids, ZnO-water and Al_2O_3-water with and without EG (ethylene glycol) on the FPSC's efficiency. The volume concentration of EG and nanoparticles were 25% and 0.25% respectively. The analysis was performed for 0.09 kg/s, 0.07 kg/s and 0.05 kg/s rate of flow. This investigation showed that by the use of EG and increment in flow rates, System efficiency was increased [6]. Mohammad Shafiey Dehaj & Mostafa Zamani Mohiabadi (2019), conducted an experiment on solar collector used with heat pipe (HPSC) and MgO-water nanofluid was used. This analysis showed that with increase the flow rate of coolant, system efficiency increases. System efficiency of heat pipe solar collector (HPSC) was achieved higher with MgO-water nanofluid than with pure water [7]. Dinesh Babu Munuswamy et al. (2020) have done an experimental analysis with two FPCs, one without fins and another with longitudinal fins were used in solar collector of 5 m^2 area. Inside the collector thermocouples of K type were used to find out the temperature changes inside the solar collector. Two nanoparticles CuO and Al_2O_3 with changing weight fractions were used. Collector with fins gained higher efficiency than without finned collector. Al_2O_3 based nanofluid gained higher efficiency than CuO based nanofluid [8].

Eric C. Okonwo et al. (2020) evaluated the system performance of FPSC by the use of water, hybrid nanofluid (alumina-iron/water) and alumina-water nanofluid. Nanoparticles are used with 0.2%, 0.1% and 0.05% fractions and thermal properties of nanofluids were estimated in changing temperature ranges. When water is compared with nanofluid and hybrid nanofluid, system thermal efficiency was reduced by 1.79% with hybrid nanofluid and 2.16% increased with alumina-water with 0.1% concentration [9]. Mohammad Reza Saffarian et al. (2020) have been used CuO/water and Al_2O_3/water nanofluids at fractions (volume) 4% and 1%. With nanofluids they also changed the flow direction in the FPSC for the enhancement in coefficient of convective heat transfer. To change the flow direction Wavy, spiral and U- shaped pipes with equal lengths are simulated on the steady state and three dimensional continuity equations, momentum and energy equations were solved. Nusselt number (Nu) and coefficient of heat transfer were increased remarkably when spiral and wavy pipes have been used. Pressure drop was highest for wavy pipes. When nanofluids have been used in place of water heat transfer coefficient was increased. This analysis also showed that Nu was decreased in all cases because of significant enhancement in thermal conductivity with the nanofluids, except with 4 % concentration of CuO [10].

2. Nanofluids

2.1 History of nanofluids:

In early days solar fluids like ethylene glycol, oil and water were used in FPSWHs for both industrial and household purposes, but theses fluids have low thermal conductivity. To improve the thermal conductivity in these solar fluids, several researches have been done and nanofluids came in to picture. Nanofluids are, in which nanoparticles (size <100 nm) are suspended in base fluid. Maxwell introduced this first time in 1881 [11].

2.2 Applications of nanofluids:

Recently to improve the system performance of FPSC several types of nanofluids are used. Due to high thermal conductivity, nanofluids have several applications. Some of these applications are: solar cells [12], solar stills [13], thermal energy storage [14], direct absorption system [15], thermoelectric cells [16], air conditioning system and circular heat exchanger [17], etc. Applications of nanofluids are shown in fig 1.

2.3 Preparation of nanofluids:

Nanofluids are formed when nanoparticles (size < 100 nm) with some % fraction mixed in base fluid. This is a colloidal mixture, in which nanoparticles are suspended into base fluid. When only one nanoparticle is used it is called single nanofluid, but recently more than one nanoparticles are used with base fluid then such nanofluids are known as hybrid (composite) nanofluids. Some times to increase stability of nanofluids and for better dispersion of nanoparticles, which are suspended in base fluid, surfactants are added. These surfactants change the transient properties such as viscosity and thermal conductivity of nanofluids. Fig. 2 shows, the several kinds of base fluids, nanofluids and surfactants are used.

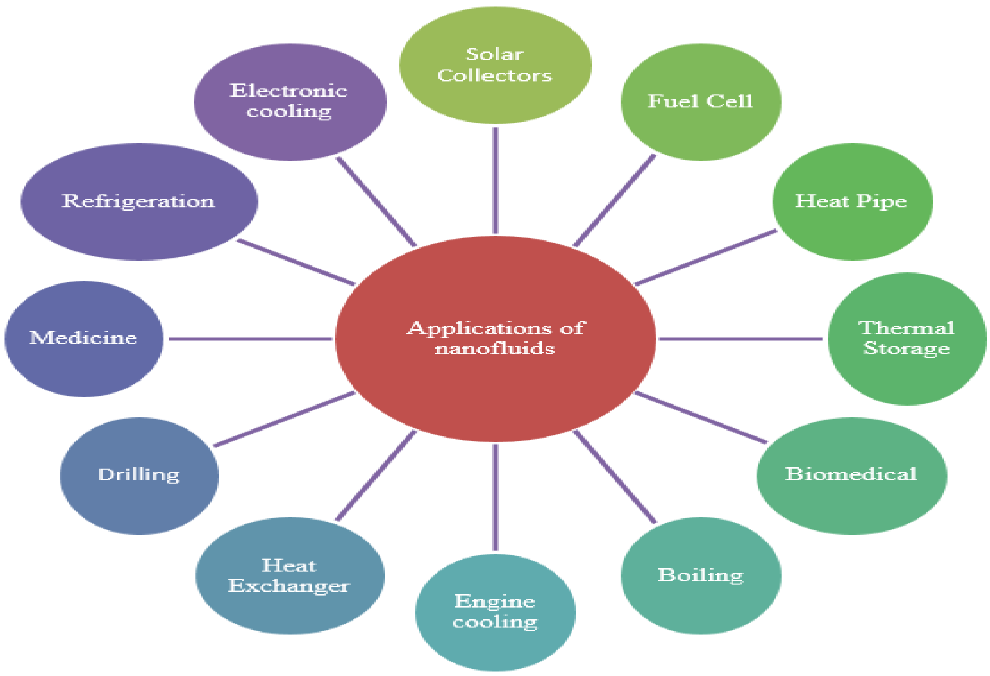

Fig.1: Applications of Nanofluids [2].

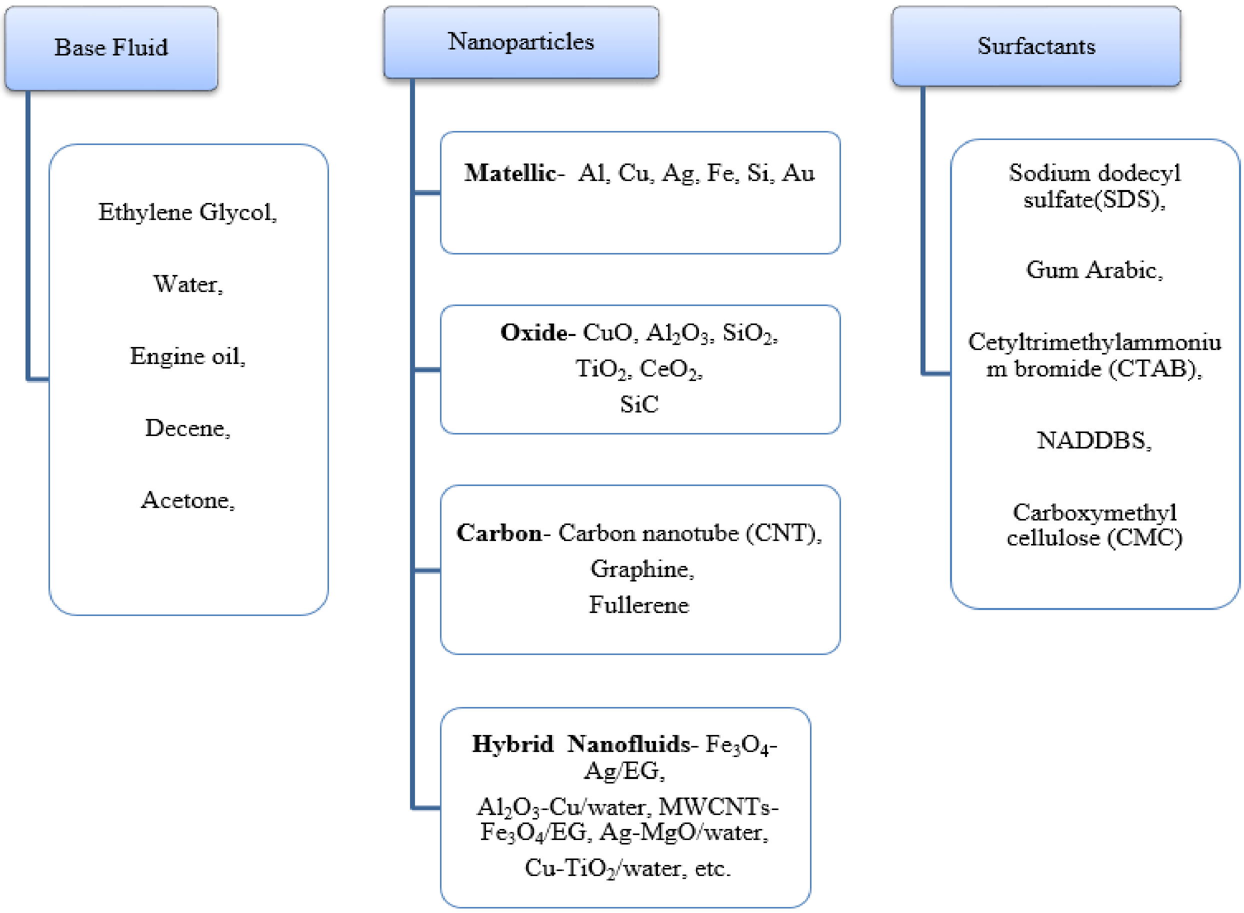

Fig. 2: Types of Base Fluids, Nanoparticles and Surfactants [2].

3. Theoretical and experimental studies done on FPSCs with nanofluids:

Several studies or analyses have been done on FPSCs when nanofluids were used. In these nanofluids, nanoparticles are put in base fluid and these nanoparticles are taken in different volume/weight concentrations, different sizes, mass flow rate and types of nanoparticles. Table 1 shows some previous studies, which have been done on FPSCs with nanofluids.

Table.1: List of previous studies on FPSC using Nanofluids [18-27]

Resource Persons	Analysis Type	Base Fluid	Details of Nanoparticles Used			Mass Flow Rate	Observations
			Type	Size (nm)	Volume/ Weight Concentration (%)		
Omid Mahian et al. (2014) [18]	Experimental	Water	Al_2O_3	25, 50, 75 and 100 nm	4% (wt)	0.1-0.8 (Kg/s)	Outlet temperature increases with the increment in volume fraction and decrease with the increment in the nanoparticle size.
Alper Meta Genc et al. (2018) [19]	Numerical	Water	Al_2O_3	-	1%, 2% and 3% (wt)	0.004 - 0.006 (Kg/s)	Maximum increment in outlet temperature achieved 7.2% at 0.004 Kg/s and 3% (concentration), and the highest system thermal efficiency achieved 83.9% at 0.006 Kg/s.

Table.1
(Continued)

Resource Persons	Analysis Type	Base Fluid	Details of Nanoparticles Used			Mass Flow Rate	Observations
			Type	Size (nm)	Volume/ Weight Concentration (%)		
Moshen MIrzaei et al. (2018) [20]	Experimental	Water	Al_2O_3	20 nm	0.1% (vol)	1, 2 and 3 (LPM)	Optimum efficiency achieved at 2 LPM and collector efficiency increased about 23.6%.
Nitesh Singh Rajput et al. (2019) [21]	Experimental	Water	Al_2O_3 with sufactant Sodium dodecyl sulfate (SDS)	10-15 nm	0.1% - 0.3% (vol)	1-3 (LPM)	When volume concentration increased from 1 to 3 %, collector efficiency increased upto 21.32%.
A.R. Naghreha-badi et al. (2016) [22]	Experimental	Water	SiO_2	12 nm	1%	Varies Between 0.35 and 2.8 (LPM)	Difference between inlet and outlet temperature decreases when rate of mass flow increases.
Sujit Kumar Verma et al. (2016) [23]	Experimental	Water	MgO	40 nm	0.25% 0.5% 0.75% 1.0% 1.25% (vol)	0.5 1.0 1.5 2.0 2.5 (LPM)	For 0.75% volume fraction and 1.5 LPM exergetic efficiency and thermal efficiency increased by 32.23% and 9.34% respectively.
M. Vakili et al. (2016) [24]	Experimental	Deionized Water	Graphene Nanoplat-eletes	-	0.0005% 0.001% 0.005% (wt)	0.0075 0.015 0.225 (Kg/s)	For both base fluid and nanofluid highest efficiency obtained at 0.15 Kg/s and nanofluid with fractions 0.0005, 0.001 and 0.005% the zero loss efficiencies are 83.5%, 89.7% and 93.2% and for base fluid it was 70%.
Nang Khin Chaw Sint et al. (2017) [25]	Experimental	Water	CuO	25 nm	0.1% 0.5% 1% and 2%	-	With the use of CuO- Water nanofluid, efficiency of FPSC enhances upto 5% as compared with water at the same working conditions.
P. Michael Joseph Stalin et al. (2017) [26]	Experimental	water	CeO_2/ Water	25 nm	0.01% (vol) 0.01% (vol)	1-3 (LPM)	78.2% maximum efficiency obtained, which was 21.5 % more as compared to water as base fluid. And this maximum efficiency achieved at 2 LPM, so 2 LPM is optimum flow rate in this case.

Table.1
(Continued)

Resource Persons	Analysis Type	Base Fluid	Details of Nanoparticles Used			Mass Flow Rate	Observations
			Type	Size (nm)	Volume/ Weight Concentration (%)		
Sujit Kumar et al. (2018) [27]	Experimental	Water	Hybrid CuO and hybrid MgO , with $MWCNT_s$	-	0.25 - 2% (vol)	0.5- 2 (LPM)	Energetic and exergetic efficiencies for CuO hybrid nanofluid were 69.11% and 70.63% and for MgO hybrid nanofluid were 70.55% and 71.54% respectively. That means performance result was better with MgO hybrid nanofluid than hybrid CuO nanofluid.

4. Conclusion

This article gives the overview of latest developments in the field of FPSC with nanofluids. By the use of nanofluids system thermal performance increases of FPSC, so nanofluid based FPSC may be used efficiently in industrial and domestic purposes. Some gained conclusions are the following:

- To increase the collector performance and absorption of solar radiation, use of appropriate nanoparticles and long- time stability should be necessary. When the stability of colloidal mixture of nanofluid is long time then it increases the system efficiency and for long time stability of nanofluids, surfactants are used.
- Collector efficiency is improved with the increment in volume concentration, but if volume concentration is increased so high, collector efficiency decreases because at high volume concentration viscous forces are increased and rate of heat transfer is decreased. Outlet temperature increases with increase in concentration (volume) and decreases with increase in the size of nanoparticles. As nanofluids have more thermal conductivity than base fluids like water, so if nanofluids are used system efficiency increases.
- Heat transfer coefficient increases if the direction of flow for nanofluids is changed. For this U shape and spiral pipes could be used in the collector. Collector with fins achieved higher efficiency than without fins.
- 5% efficiency of FPSC improves, if instead of water (working fluid), CuO- water nanofluid is used.
- Since energetic and exergetic efficiencies for CuO hybrid nanofluid were 69.11% and 70.63% and for MgO hybrid nanofluid were 70.55% and 71.54%, which denotes that MgO hybrid nanofluid performs well.
- At 0.1% concentration for Al_2O_3 - water nanofluid, efficiency increased 2.16% and for hybrid nanofluid (Al_2O_3-Fe/water) efficiency decreased 1.79% as compared with water (working fluid).

REFERENCES:

1. Maxime Mussard, Solar energy under cold climate conditions: A review. Renewable and sustainable Energy reviews 74, (2017), 733-745, http://dx.doi.org/10.1016/j.rser.2017.03.009.
2. Ahmed M. Ajeena, Piroska Vig, Istvan Farkas, A comprehensive analysis of nanofluids and their practical applications for flat plate solar collector: Fundamentals, thermo physical properties, stability and difficulties. Energy Reports 8, (2022), 4461-4490, https://doi.org/10.1016/j.egyr.2022.03.088.
3. Eastman, J.A., 2014. Enhancing thermal conductivity of fluids with nanoparticles. In: ASME International Mechanical Engineering Congress & Exposition, November 1995, 12-17, San Francisco, CA 2014.
4. Yijie Tong, Xiaoni Chi, Woobin Kang, Honghyun Cho, Comparative investigation of efficiency sensitivity in a flat plate solar collector according to nanofluids. Applied Thermal Engineering 174 (2020), 115346, https://doi.org/10.1016/j.applthermaleng.2020.115346.
5. M. Faizal, R Saidur, S. Mekhief, M.A. Alim, Energy, economy and environmental analysis of metal oxides .nanofluid for flat -plate solar collector. Energy Conversion and Management 76, (2013), 162-168, http://dx.doi.org/10.1016/j.enconman.2013.07.038.
6. Erdogan Arikan, Serkan Abbasoglu, and Mustafa Gazi, Experimental performance analysis of flat plate solar collectors using different nanofluids. Sustainability 10, (2018), 1794, http://dx.doi.org/10.3390/su10061794.
7. Mohammad Shafiey Dehaj, Mostafa Zamini Mohiabadi, Experimental investigation of heat pipe solar collector using MgO nanofluids. Solar Energy Materials and Solar Cells 191, (2019), 91-99, https://doi.org/10.1016/j.solmat.2018.10.025.

8. Dinesh Babu Munuswamy, Yuvarajan Devarajan, M. Naresh Babu, Sathiyamoorthi Ramalingam, Experimental investigation on lowering the environmental hazards and improving the performance patterns of solar flat plate collectors by employing the internal longitudinal fins and nano additives. Environmental Science and Pollution Research (2020), https://doi.org/10.1007/s11356-020-10311-3.
9. Eric C. Okonkwo, Ifeoluwa Wole-Osho, Doga Kavaz, Muhammad Abid, Tareq Al- Ansari, Thermodynamic evaluation and optimization of a flat plate collector operating with alumina and iron mono and hybrid nanofluids. Sustainable Energy Technologies and Assessment 37, (2020), 100636, https://doi.org/10.1016/j.seta.2020.100636.
10. Mohammad Reza Saffarian, Mojtaba Moravej, Mohammad Hossein Doranehgard, Heat transfer enhancement in a flat plate collector with different flow path shapes using nanofluid, Renewable Energy 146, (2020), 2316-2329, https://doi.org/10.1016/j.renene.2019.08.081.
11. Choi, S.U.S., 1995. Enhancing thermal conductivity of fluids with nanoparticles. Am. Soc. Mech. Eng. Fluids Eng. Div. (Publ.) FED 231, 99–105, http://refhub.elsevier.com/S2352-4847(22)00644-8/sb30.
12. Otanicar, T.P., Golden, J.S., 2009. Comparative environmental and economic analysis of conventional and nanofluid solar hot water technologies. Environ. Sci. Technol. 43, 6082–6087, http://dx.doi.org/10.1021/es900031j.
13. Gnanadason, M.K., Kumar, P.S., Jemilda, G., Sherin Jasper, S., 2012. Effect of nanofluids in a modified vacuum single basin solar still. Int. J. Sci. Eng. Res. 3, 1–7, http://refhub.elsevier.com/S2352-4847(22)00644-8/sb58.
14. Donghyun Shin, Debjyoti Banerjee, Enhancement of specific heat capacity of high temperature silica nanofluids synthesized in alkali chloride salt eutectics for solar thermal- energy storage applications. Heat and Mass Transfer 54, (2011), 1064-1070, http://dx.doi.org/10.1016/j.ijheatmasstransfer.2010.11.017.
15. Duangthaongsuk, W. Wongwises, S., Measurement of temperature dependent thermal conductivity of TiO_2-water nanofluids, Experimental Thermal Fluid Science 33, (2009), 706-714, http://dx.doi.org/10.1016/j.expthermflusci. 2009.01.005 .
16. Hongnan Fan, Randeep Singh, Aliakbar Akbarzadeh, Electric power generation from thermoelectric cells using a solar dish concentrator. Journal of Electronics Materials, vol 40, No. 5, (2011), http://dx.doi.org/10.1007/s11664-011-1625-x.
17. Faizan Ahmed, Waqar Ahmed Khan, Efficiency enhancement of an air- conditioner utilizing nanofluids: An experimental study. Energy Reports 7 (2021), 575-583, https://doi.org/10.1016/j.egyr.2021.01.023.
18. Omid Mahian, Ali Kianifar, Ahmmet Z. Sahin, Somchai Wongwises, Entropy generation during Al_2O_3/water nanofluid flow in a solar collector: Effects of tube roughness nanoparticle size and different thermophysical models. International journal of Heat and Mass Transfer 78, (2014), 64-75, http://dx.doi.org/10.1016/j.ijheatmasstransfer.2014.06.051.
19. Alper Mete Genc, Mehmet Akif Ezan, Alpaslan Turgut, Thermal performance of a nanofluid-based flat plate solar collector: A transient numerical study. Applied Thermal Engineering 130, (2018), 395-407, https://doi.org/10.1016/j.applthermaleng.2017.10.166.
20. Mohsen Mirzaei, Seyed Mohmmad Sadegh Hosseini, Amir Mansour Moradi Kashkooli, Assessment of Al_2O_3 nanoparticles for the optimal operation of the flat plate solar collector. Applied Thermal Engineering 134, (2018), 68-77, https://doi.org/10.1016/j.applthermaleng.2018.01.104.
21. Nitesh Singh Rajput, Dipesh Dilipbhai Shukla , Deep Rajput, Shiv Kumar Sharma, Performance Analysis of flat plate solar collector using Al_2O_3/ Distilled water nanofluid: An experimental investigation. Material Today: Proceedings 10, (2019), 52-59, https://doi.org/10.1016/j.matpr.2019.02.188.
22. A.R. Noghrehabadi, E. Hajidavaloo and M. Moravej, Experimental investigation of efficiency of square flat plate solar collector using SiO_2/water nanofluid, case studies in Thermal Engineering, http://dx.doi.org/10.1016/j.csite.2016.08.006.
23. Sujit Kumar Verma, Arun Kumar Tiwari, Durg Singh Chauhan, Performance augmentation in flat plate solar collector using MgO/water nanofluid. Energy Conversion and Management 124, (2016), 607-617, http://dx.doi.org/10.1016/j.enconman.2016.07.007.
24. M. Vakili., S. M. Hosseinalipour, S. Delfani, S. Khosrojerdi, M. Karami, Experimental investigation of grapheme nanoplatelets nanofluid- based volumetric solar collector for domestic hot water systems. Solar Energy 131, (2016) , 119-130, http://dx.doi.org/10.1016/j.solener.2016.02.034.
25. Nang Khin Chaw Sint, I.A. Choudhury, H.H. Masjuki, H. Aoyama, Theoretical analysis to determine the efficiency of a CuO- Water nanofluid based- flat plate solar collector for domestic solar water heating systems in Myanmar. Solae Energy 155, (2017), 608-619, http://dx.doi.org/10.1016/j.solener.2017.06.055.
26. P. Michel Joseph Stalin, T. V. Arjunan, M. M. Matheswaran, N. Sadanandam, Experimental and theroretical investigation on the effects of lower concentration CeO_2/water nanofluid in flat plate solar collector. Journal of Thermal Analysis and Calorimetry (2017), https://doi.org/10.1007/s10973-017-6865-4.
27. Sujit Kumar Verma, Arun Kumar Tiwari, Sandeep Tiwari, Durg Singh Chauhan, Performance analysis of hybrid nanofluids in flat plate solar collector as an advanced working fluid. Solar Energy 167, (2018), 2310241, https://doi.org/10.1016/j.solener.2018.04.017.