International Journal of Science and Research Archive

eISSN: 2582-8185

Cross Ref DOI: 10.30574/ijsra

Journal homepage: https://ijsra.net/

(RESEARCH ARTICLE)

Check for updates

Impact of water based nanofluids in heat exchanger type active solar PV cooling systems: A comparative CFD analysis

Vimukthi Vithanage [1, 2, 3], Shen Hosan [1], Hasith Perera [1], Chanaka Galpaya [2, 3], Ashan Induranga [1, 2, 3], Amalka Indupama [1, 2, 3], Dasith Wijesekara [1, 2] and Kaveenga Koswattage [1, 2 *]

[1] *Faculty of Technology, Sabaragamuwa University of Sri Lanka, Belihuloya 70140, Sri Lanka.*
[2] *Center for Nano Device Fabrication and Characterization (CNFC), Faculty of Technology, Sabaragamuwa University of Sri Lanka, Belihuloya 70140, Sri Lanka.*
[3] *Faculty of Graduate Studies, Sabaragamuwa University of Sri Lanka, Belihuloya 70140, Sri Lanka.*

International Journal of Science and Research Archive, 2025, 14(01), 1139-1145

Publication history: Received on 08 December 2024; revised on 18 January 2025; accepted on 21 January 2025

Article DOI: https://doi.org/10.30574/ijsra.2025.14.1.0148

Abstract

Solar photovoltaic technology is a fast growing form of renewable energy with many positive factors such as low cost, environmental friendliness, energy independence, etc. But, one of the major drawbacks of solar photovoltaic technology is the less efficiency compared to other forms of renewable energy technologies. There are many factors affecting the efficiency of a solar PV system such as temperature, solar irradiance, material quality, reflection losses, cell design etc. Researchers are focusing on different aspects to control the above factors to improve the efficiency of solar PV systems. Solar photovoltaic cooling system is one such solution which can be used to control the operating temperature of solar photovoltaic cells. The most common coolant used in these systems is water due to its superior thermo physical properties. In this research we are focusing on improvement of the thermophysical properties of water using nanotechnology. This article presents a CFD (Computational Fluid Dynamics) analysis conducted for a heat exchanger type solar PV cooling system integrated with a solar photovoltaic panel for water based nanofluids mainly focusing on three metal oxide nanoparticles Al_2O_3, CuO, and TiO_2. Initially the heat exchanger model was developed using Solid Edge 2022 software and the thermo physical properties were simulated using Ansys 2019 software for different water based nanofluids. The obtained results were analyzed comparatively with the performance of water as a coolant in the same heat exchanger system. The results conclude that metal oxide/water based nanofluids have comparatively better thermal properties than water and can be suggested as possible alternatives for water in closed loop heat exchanger applications.

Keywords: CFD simulation; Solar photovoltaics; Cooling systems; Nanofluids

1. Introduction

The operating temperature of solar PV cells is one of the major factors affecting the power output of solar PV systems, as the increasing operating cell temperature leads to a decrease in solar cell efficiency [1][2]. Many researches have been conducted on different types of solar PV cooling systems such as forced/natural air cooling [3][4], water spray/flow cooling [5][6], heat exchanger type [7][8][9], water immersion type [10], floating solar [11] etc. to optimize the operation efficiency by controlling the operating temperature of solar PV panels. Most of these technologies have proven the ability to control the operating temperature of solar cells, but there are several practical and financial limitations to introduce these technologies to commercial solar PV systems. Among these studies on different PV cooling technologies, heat exchanger-type solar PV cooling systems have shown comparatively higher system efficiency due to the possibility of utilizing the dissipated heat energy from solar panels for external applications. Water is the most commonly used coolant liquid for heat exchangers in industrial applications due impressive thermo-physical properties

* Corresponding author: Kaveenga Koswattage

and cost effectiveness. With the development of nano-technology, nano-fluids, which can be defined as liquids that have suspended nano-solid particles, are emerging as promising future heat transfer fluids with superior thermo-physical properties. In recent studies, water-based nano-fluids, with metal-oxide nanoparticles, and metal nanoparticles and carbon-based nanoparticles, such as Al_2O_3/water, Fe_3O_4/water, TiO_2/water, GO/water, CuO/ water, carbon nanotubes, etc. have shown impressive thermo-physics properties with respect to water [12][13][14].

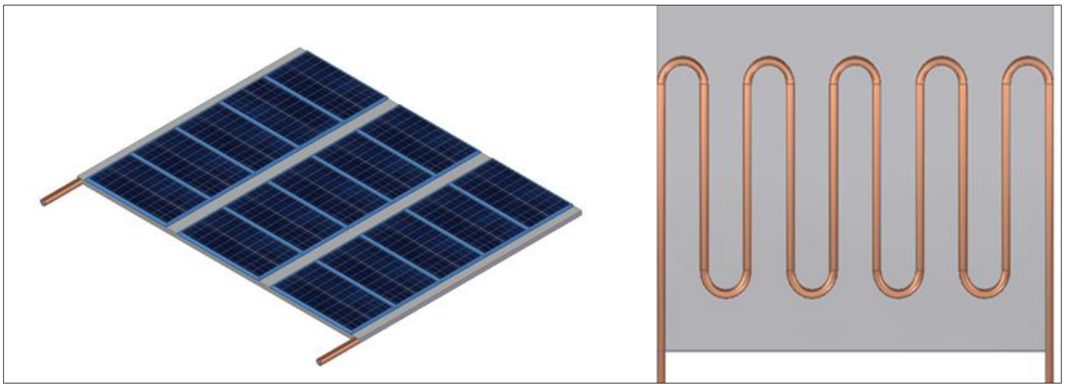

Figure 1 Solar PV module integrated with heat exchanger unit (top view and bottom view)

The objective of this study is to conduct a computational fluid dynamics analysis of the physical characteristics and the heat transfer characteristics of fluid flow in a pilot-scale solar PV cooling system which is designed as an integrated unit with the solar PV module. The solar PV cooling system used for this study is designed as a closed loop, active, heat exchanger type system as shown in Fig. 1. The Ansys 2019 software was used for the CFD analysis to determine the effect on heat transfer and pressure drop for three different water based nano-fluids, Al_2O_3/water,TiO_2/water, and CuO/ water. A comparative analysis was conducted on the performance of each of the water-based nano-fluids and water (base fluid) through thermal flow profiles and hydrodynamic flow profiles to study the possibility of using water-based nano-fluids as an improved alternative to water. There are similar studies, and CFD analyses conducted for various water-based nano-fluids as a coolant liquid for heat exchange applications which have shown improved heat exchange properties [15][16][17]. The results of this study highlight the potential of using nano-fluids as heat transfer fluids in heat exchange applications in the solar PV industry as it makes it possible to develop financially feasible cooling solutions for solar PV modules. The arrangement of the paper is as follows, section 02 discusses the methodology and section 03 discusses the post-processing results. The conclusion of this study and the acknowledgment are given in section 04 and section 05 respectively.

2. Methodology

The solar PV heat exchanger model was initially designed in Solid Edge 2022 student edition software and it was compiled with Ansys 2019 R3.

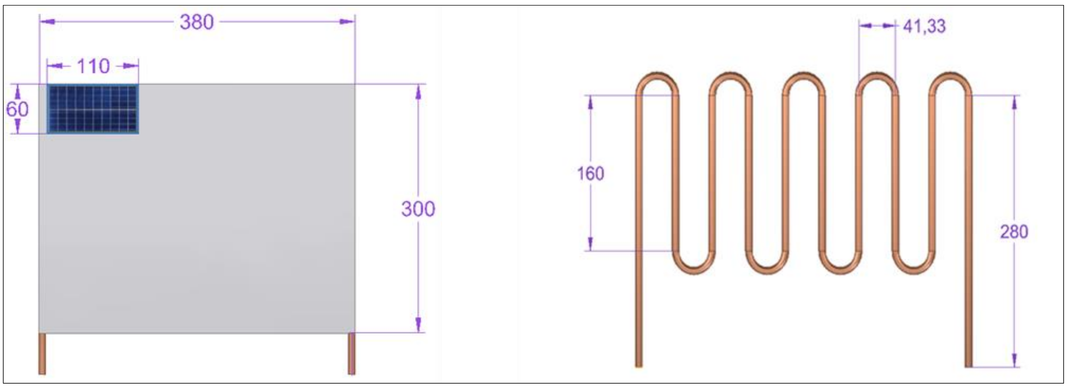

Figure 2 Dimensions of the designed cooling plate, copper tube and heat exchanger

The prototype is designed as an integrated unit with fifteen (15) monocrystalline solar PV cells and an aluminum cooling plate which is designed as a copper tube heat exchanger in the bottom of the solar PV module as illustrated in Fig.1 and Fig. 2. The dimensions of the copper tube are illustrated in Fig.3 below. The cooling plate was designed with a plate thickness of 0.5 mm, Aluminum material and the heat pipe was designed with copper, 1mm thickness. Table 1 and Table 2 show the thermo-physical properties of Al_2O_3/water, TiO_2/water, and CuO/ water nano-fluids for 0.5 v/v% and 1.0 v/v% concentrations and Table 3 shows the thermo-physical properties of Al_2O_3, TiO_2, and CuO. The numerical data for the thermo-physical properties were obtained from the studies by S Anis et al [18] ,Jefferson Raja Bose et al [19] and Valiyollah Ghazanfari et al [20].

Table 1 Specifications of nanofluids for 0.5 v% [18][19]

Type of Nanofluid	$Ti0_2$/Water	Al_2O_3/Water	CuO/Water
Density (kg/m3)	1015.24	1013.06895	1038.86
Viscosity (kg/m.s)	0.00095	0.0010427	0.000953
Specific Heat (J/kg.K)	4105.48	4110.346	4014.45
Thermal Conductivity (W/m.K)	0.6117	0.67	0.6196

Table 2 Specifications of nanofluids for 1.0 v% [18][19]

Type of Nanofluid	$Ti0_2$/Water	Al_2O_3/Water	CuO/Water
Density (kg/m3)	1031.4	1027.9279	1078.64
Viscosity (kg/m.s)	0.00096	0.00108855	0.000964
Specific Heat (J/kg.K)	4035.24	3943.25	3862.97
Thermal Conductivity (W/m.K)	0.6259	0.70	0.6363

Table 3 Specifications of nano-particles [18][20]

Type of Nano-particle	$Ti0_2$	Al_2O_3	CuO
Density (kg/m^3)	4250	3970	6500
Specific Heat (J/kg.K)	686.2	525	535.6
Thermal Conductivity (W/m.K)	8.95	17.65	20

Initially the CAD model was developed using the Solid Edge 2022 student edition. The developed CAD model was used in Ansys 2019 for the CFD analyzing process by importing the assembly geometry file into the Ansys software. For the analyzing process, Fluid Flow (Fluent) was used as the analyzing system and Fluent was selected as the solver. The next step of the methodology is the meshing procedure which mainly affects the accuracy simulation results where higher accuracy can be obtained by small-scale meshing process [18]. In the meshing process, named faces were defined, mainly the heat surface, inlet face, and outlet face. The case of meshing used was multizone mesh, for the fluid domain and copper pipe channel. As well a case of meshing used standard mesh with an element size of 1 mm. Finally, before finalizing the meshing, studied the contact regions through the connections and removed the unnecessary automatically created contact regions. In the next setup, initially turned on the energy option in the model and set the flow as a laminar flow and assigned the materials to the respective geometrical bodies. After that, the boundary conditions were defined as 0.5 m/s inlet fluid velocity and 298 K inlet fluid ttempérature. The initial solar panel bottom temperature was set to 353 K as the solar PV panels can reach up to 80 ^{0}C during the operation when exposed to sunlight. In the initialization stage, selected the compute from the inlet and calculation programmed using transient mode through 1000 Number of Time Steps,0.1 Time Step Size (s) and Max Iterations/Time Step as 150, during this process improved the mesh quality using check mesh and improved mesh quality inbuilt functions as TUI commands for increase the accuracy of the results. In the final stage, the evaluation of the results was completed through CFD-Post and used mainly contours, as well as, used streamlines, vectors, volume rendering, and cross-sections for visual, and graphical analysis of the results on demand.

3. Results and Discussion

The analysis was conducted for both the temperature variation of the cooling plate top surface (Fig 3) which directly affects the operating temperature of the solar PV modules and the pressure variation throughout the heat pipe (Fig 6.) which is a major deciding factor of the power consumption of the active heat exchanger unit. The CFD results obtained for different nano-fluids under different volumetric concentrations clearly indicate the positive effect of adding nano additives to the water for heat transfer. When considering the minimum temperature decrease of the cooling plate surface, compared to minimum temperature decrease of water respectively, Al_2O_3/water (0.5 v/v%), CuO /water (0.5 v/v%), TiO_2/water (0.5 v/v%), Al_2O_3/water (1.0 v/v%), CuO/water (1.0 v/v%), TiO2/water (1.0 v%) resulted 5.77%, 0.96%, 1.6%, 8.33%, 2.44%, 3.21% respectively. The highest temperature decrease of the PV module bottom plate was displayed by Al_2O_3/water (1.0 v/v%) according to the results obtained through the simulation. This improvement in temperature decrease will make a significant impact on the efficiency of solar PV modules' operating temperature.

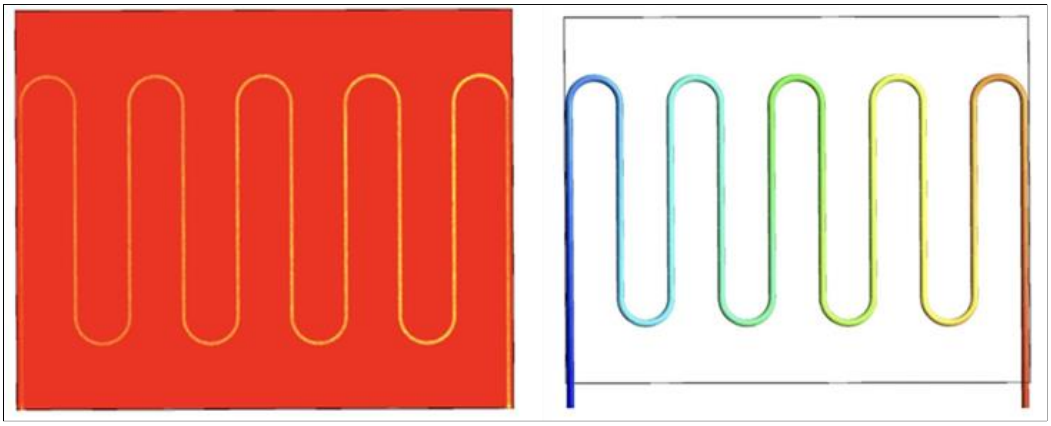

Figure 3 Temperature and pressure variation of the heat exchanger unit

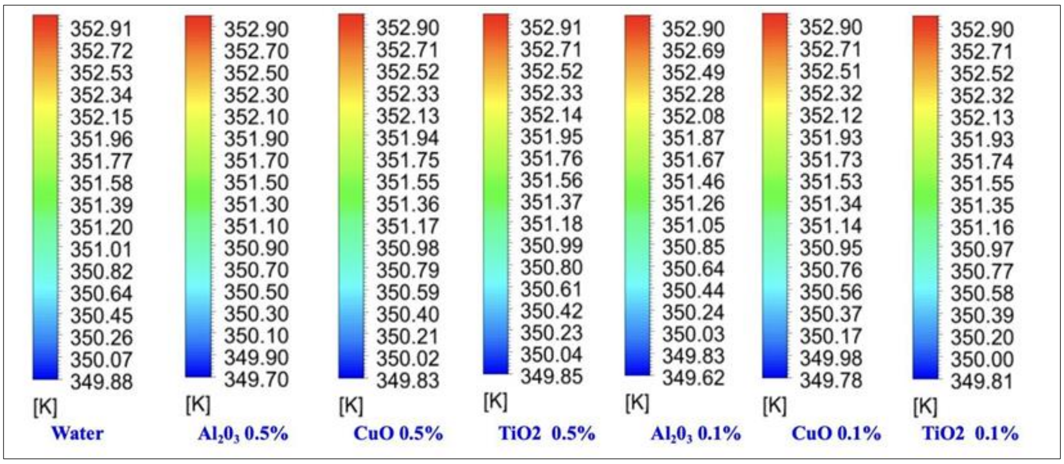

Figure 4 Temperature variation analysis of the cooling plate top surface

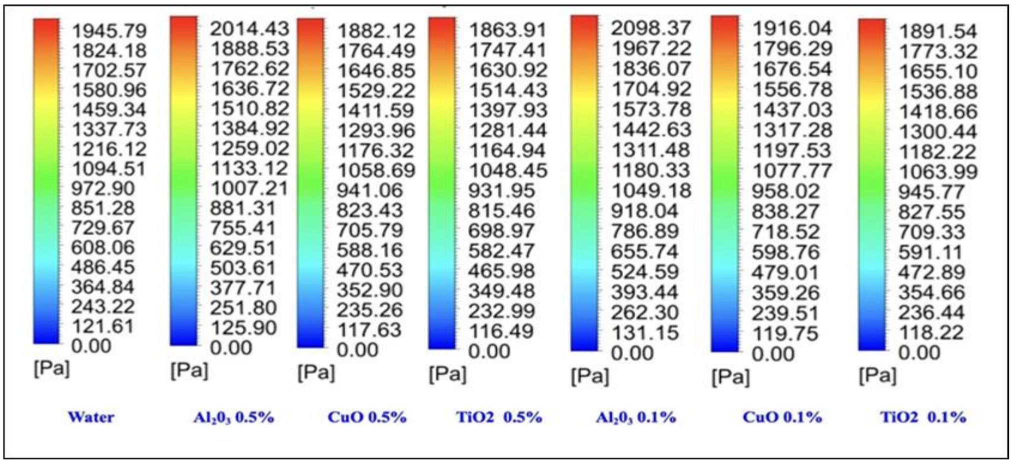

Figure 5 Pressure variation analysis of the heat exchanger copper pipe

The results for the increase of heat transfer rate of the heat exchanger unit for three different nanofluids compared to water were respectively 5.26%, 0.71%, 1.40%,6.07%, 1.99%, 2.85% for Al_2O_3/water (0.5 v/v%), CuO /water (0.5 v/v%), TiO_2/water (0.5 v/v%), Al_2O_3/water (1.0 v/v%), CuO/water (1.0 v/v%), TiO_2/water (1.0 v%) nanofluids. The heat transfer rate of Al_2O_3/water resulted the higher value compared to other nanofluids. Also, the total pressure difference between the inlet and outlet of the heat pipe was observed which is a curtail parameter to study the energy consumption of this active cooling system. The increase of pressure difference was calculated as a comparative value of pressure difference when water is used as the coolant. The total pressure difference for each of the nanofluid compared to water respectively, 3.53%, 7.82%, -4.14%,-2.86%, -3.45% , -1.61% for Al_2O_3/water (0.5 v/v%), CuO /water (0.5 v/v%), TiO_2/water (0.5 v/v%), Al_2O_3/water (1.0 v/v%), CuO/water (1.0 v/v%), TiO2/water (1.0 v%) nanofluids.When considering the pressure difference, Al_2O_3/water nanofluid shows an increased pressure drop compared to water and both the other nanofluids have a lesser pressure drop compared to water.

4. Conclusion

The following conclusions can be made based on the results obtained through simulating the above heat exchanger unit integrated with solar PV modules for Al_2O_3/water, CuO /water, TiO_2/water nanofluids under two different concentrations 0.5 v/v% and 1.0 v/v%.

- Metal oxide/water nanofluids can perform well in heat exchanger units showing better thermos-physical properties compared to water.
- Metal oxide/water nanofluids show better thermal properties with the increase of nanoparticle concentration.
- The pressure drop of the metal oxide/water nanofluids flow increases with the increase of nanoparticle concentration.
- The pressure drop metal oxide/water nanofluids were comparatively lesser than water for CuO/water ,TiO_2/water nanofluids for the simulated v/v% concentrations.
- Nanofluids can be proposed as a better alternative for water, to use in solar PV cooling systems which enables to make more efficient active cooling systems.

As the nanofluids simulation results improved thermos-physical properties compared to water, nanofluids can be identified as a better alternative for solar PV cooling systems which can improve the total system efficiency by minimizing the power consumption of the cooling system. But there are many other factors to consider when replacing water with water based nanofluids such as stability of nanofluids, environmental conditions, economic conditions, health and safety, etc.

Compliance with ethical standards

Acknowledgments

This research study was funded by the Science and Technology Human Resource Development Project, Ministry of Education, Sri Lanka, funded by the Asian Development Bank (Grant No: CRG-R2-SB-1).

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Alhmoud, L. (2023). Why does the PV solar power plant operate ineffectively? Energies, 16(10), 4074. doi:10.3390/en16104074

[2] Ionel Laurentiu Alboteanu, Constantin Florin Ocoleanu, Cornelia Aida Bulucea, "Cooling system for photovoltaic module" University of Craiova, Craiova, ISBN: 978-1-61804-110-4

[3] Arifin, Z., Tjahjana, D. D. D. P., Hadi, S., Rachmanto, R. A., Setyohandoko, G., & Sutanto, B. (2020). Numerical and experimental investigation of air cooling for photovoltaic panels using aluminum heat sinks. International Journal of Photoenergy, 2020, 1–9. doi:10.1155/2020/1574274

[4] Hussien, A., Eltayesh, A., & El-Batsh, H. M. (2023). Experimental and numerical investigation for PV cooling by forced convection. Alexandria Engineering Journal, 64, 427–440. doi:10.1016/j.aej.2022.09.006

[5] Benato, A., Stoppato, A., De Vanna, F., & Schiro, F. (2021). Spraying Cooling System for PV Modules: Experimental Measurements for Temperature Trends Assessment and System Design Feasibility. In Designs (Vol. 5, Issue 2, p. 25). MDPI AG. https://doi.org/10.3390/designs5020025

[6] Hadipour, A., Rajabi Zargarabadi, M., & Rashidi, S. (2021). An efficient pulsed- spray water cooling system for photovoltaic panels: Experimental study and cost analysis. In Renewable Energy (Vol. 164, pp. 867–875). Elsevier BV. https://doi.org/10.1016/j.renene.2020.09.021

[7] Roslan, E., & Hassim, I. (2019). Solar pv system with pulsating heat pipe cooling. In Indonesian Journal of Electrical Engineering and Computer Science (Vol. 14, Issue 1, p. 311). Institute of Advanced Engineering and Science. https://doi.org/10.11591/ijeecs.v14.i1.pp311-318

[8] Alizadeh, H., Ghasempour, R., Shafii, M. B., Ahmadi, M. H., Yan, W.-M., & Nazari, M. A. (2018). Numerical simulation of PV cooling by using a single-turn pulsating heat pipe. In International Journal of Heat and Mass Transfer (Vol. 127, pp. 203–208). Elsevier BV. https://doi.org/10.1016/j.ijheatmasstransfer.2018.06.108

[9] Ahmed, A. M., & Hassan Danook, S. (2018). Efficiency improvement for solar cells panels by cooling. In 2018 2nd International Conference for Engineering, Technology and Sciences of Al-Kitab (ICETS). IEEE. https://doi.org/10.1109/icets.2018.8724625

[10] Sivakumar, B., Navakrishnan, S., Cibi, M. R., & Senthil, R. (2021). Experimental study on the electrical performance of a solar photovoltaic panel by water immersion. In Environmental Science and Pollution Research (Vol. 28, Issue 31, pp. 42981–42989). Springer Science and Business Media LLC. https://doi.org/10.1007/s11356-021-15228-z

[11] Sasmanto, A. A., Dewi, T., & Rusdianasari. (2020). Eligibility Study on Floating Solar Panel Installation over Brackish Water in Sungsang, South Sumatra. In EMITTER International Journal of Engineering Technology (Vol. 8, Issue 1, pp. 240–255). EMITTER International Journal of Engineering Technology. https://doi.org/10.24003/emitter.v8i1.514

[12] Sahin, F., Genc, O., Gökcek, M., & Çolak, A. B. (2023). An experimental and new study on thermal conductivity and zeta potential of Fe3O4/water nanofluid: Machine learning modeling and proposing a new correlation. In Powder Technology (Vol. 420, p. 118388). Elsevier BV. https://doi.org/10.1016/j.powtec.2023.118388

[13] Yogesh Kokate, S B Sonawane (2023), Investigation of particle size effect on thermal conductivity enhancement of distilled water-Al2O3 nano fluids. Fluid Mechanics Research International Journal. Volume 3 Issue 2 - 2019.

[14] Dongsheng Wen, & Yulong Ding. (2006). Natural convective heat transfer of suspensions of titanium dioxide nanoparticles (nanofluids). In IEEE Transactions On Nanotechnology (Vol. 5, Issue 3, pp. 220–227). Institute of Electrical and Electronics Engineers (IEEE). https://doi.org/10.1109/tnano.2006.874045

[15] Patricia Anne D. Cruz, Ed-Jefferson E. Yamat, Jesus Patrick E. Nuqui, Allan N. Soriano, Computational Fluid Dynamics (CFD) analysis of the heat transfer and fluid flow of copper (II) oxide-water nanofluid in a shell and tube heat exchanger,Digital Chemical Engineering,Volume 3,2022

[16] Valiyollah Ghazanfari, Armin Taheri, Younes Amini, Fatemeh Mansourzade, Enhancing heat transfer in a heat exchanger: CFD study of twisted tube and nanofluid (Al2O3, Cu, CuO, and TiO2) effects, Case Studies in Thermal Engineering,Volume 53,2024

[17] Ramisha Sajjad, Muzamil Hussain, Sami Ullah Khan, Abdul Rehman, Muhammad Jahangir Khan, Iskander Tlili, Sami Ullah, CFD analysis for different nanofluids in fin prolonged heat exchanger for waste heat recovery, South African Journal of Chemical Engineering, Volume 47,2024

[18] S. Anis, Y. C. Kayunda, A. Kusumastuti, and J. P. Simanjutak, "Simulation study of Al2O3-H2O nanofluids as radiator coolant using computational fluid dynamics method," in IOP Conf. Ser.: Earth Environ. Sci., vol. 969, The 10th Engineering International Conference, Semarang, Indonesia (VIRTUAL), 23 Sept. 2021. Published under licence by IOP Publishing Ltd, 2022, p. 012026. DOI: 10.1088/1755-1315/969/1/012026.

[19] Bose, J.R.; Manova, S.; Angeline, A.A.; Asirvatham, L.G.; Gautam, S. Numerical Study on the Heat Transfer Characteristics of Cu-Water and TiO2-Water Nanofluid in a Circular Horizontal Tube. Energies2023,16,1449. https:// doi.org/10.3390/en16031449

[20] Valiyollah Ghazanfari, Armin Taheri, Younes Amini, Fatemeh Mansourzade,Enhancing heat transfer in a heat exchanger: CFD study of twisted tube and nanofluid (Al2O3, Cu, CuO,and TiO2) effects,Case Studies in Thermal Engineering,Volume 53,2024,https://doi.org/10.1016/j.csite.2023.103864.