Co-published by
Institute of Fluid-Flow Machinery
Polish Academy of Sciences
Committee on Thermodynamics and Combustion
Polish Academy of Sciences

http://www.imp.gda.pl/archives-of-thermodynamics/

ARCHIVES OF THERMODYNAMICS

Experimental Analysis of Energy Output in Evacuated Tube Heat Pipe Collector with Nanofluids

Shamkant Desale[a*], Premendra Bansod[a], Arakerimath Rachyya[b], Srinidhi Campli[c]

[a]Mechanical Engineering Department,G H Raisoni College of Engineering & Management, Savitribai Phule University, Pune, Maharashtra 412207, India
[b]Mechanical Engineering Department, JSPM Rajshi Shahu College of Engineering, Pune, Maharashtra 411033, India
[c]Faculty of Mechanical and Electrical Engineering, College of Military Engineering, Pune, Maharashtra 411031, India
*Corresponding author email: shamdesale27@gmail.com

Received: 10.06.2025; revised: 05.03.2026; accepted: 09.04.2026

Abstract

Solar heating devices have been extensively investigated to maximise energy utilisation and improve overall thermal efficiency. The present study aims to evaluate the performance of an evacuated tube heat pipe collector with nanofluid and compare it with a conventional heat pipe collector operating without nanofluid, with particular emphasis on the water outlet temperature. In the available literature, several studies have examined the effects of parameters such as the collector inclination angle, nanofluid concentration, and water inlet temperature on the thermal performance of evacuated tube solar collectors. However, a comprehensive comparative analysis incorporating all these parameters on a common experimental platform has not been adequately reported. In the present work, the variation in outlet temperature was systematically analysed by considering independent parameters such as the angle of inclination, copper oxide (CuO) nanofluid concentration, and water inlet temperature. Furthermore, the analysis of variance (ANOVA) was performed on the experimental dataset to evaluate the statistical significance and reliability of the obtained results.

Keywords: Evacuated pipe; ANOVA; Regression analysis; Heat pipe

Vol. 47(2026), No. 2, 159–165; doi: 10.24425/ather.2026.158682

Cite this manuscript as: Desale, S., Bansod, P., Rachyya, A., & Campli, S. (2026). Experimental Analysis of Energy Output in Evacuated Tube Heat Pipe Collector with Nanofluids. *Archives of Thermodynamics*, 47(2), 159−165.

1. Introduction

Solar energy is abundantly available in nature and serves as one of the most promising renewable energy sources. Efficient utilisation of solar energy at a low investment cost and with enhanced thermal efficiency has become increasingly important. Evacuated tube solar collectors are widely used to capture solar thermal energy for water heating applications. These systems can significantly improve thermal performance in industrial processes by conserving thermal energy, reducing operational time, and extending equipment lifespan. The thermal efficiency of solar energy systems has become a major focus in renewable energy research. The basic principle of solar heat collection involves the absorption of solar radiation by a surface, resulting in an increase in temperature. Solar water heating systems are available in several configurations, among which heat pipe-based evacuated tube collectors have attracted considerable attention because of their superior heat transfer characteristics.

Heat pipes are extensively used in thermal management applications such as automobiles, electronic cooling systems, and laptop computers. With rapid advancements in technology, efficient thermal energy transfer has become essential in heat pipe technology. Nanomaterials are increasingly utilised as additives in working fluids such as water, engine oil and ethylene glycol to improve thermal performance. Nanoparticles such as silicon carbide and copper oxide possess superior thermal conductivity

Nomenclature

C_p – specific heat of water, J/(kg K)
M_w – mass of water, kg
Q – solar energy, J
T – temperature of water, K

Subscripts and Superscripts

1, 2, 3, 4 – number of heat pipe
in – inlet, input
out – outlet
u – useful

Abbreviations and Acronyms

ANOVA – analysis of variance
SEM – scanning electron microscope
S/N – signal-to-noise
XRD – X-ray diffraction

compared to conventional base fluids, thereby enhancing heat transfer efficiency. A heat pipe operates on the principle of two-phase heat transfer, where the working fluid continuously undergoes evaporation and condensation within a closed system. When the evaporator section of the heat pipe is heated, the working fluid vaporises, increasing vapour pressure. The vapour then travels through the adiabatic section to the condenser region, where it releases latent heat and condenses back into liquid form. The condensed liquid subsequently returns to the evaporator section through gravity or capillary action, completing the cycle. The use of nanofluids as working fluids significantly improves the thermal performance of heat pipes because of their enhanced thermal conductivity and heat transfer properties.

Today, solar energy systems are gaining considerable importance because of their availability, economic viability, efficiency, and environmental sustainability in reducing carbon emissions and harmful gases. Elbrashy et al. [1] investigated the thermal performance of a solar air heater integrated with evacuated tubes and nano-enhanced copper oxide phase change material as a thermal storage enhancer. The nano-enhanced material was placed between the inlet and outlet flow passages to improve heat transfer rates, resulting in a thermal efficiency of 62.66%. Yurddas et al.[2] studied and optimised the thermal performance of evacuated tube solar collectors using various nanofluids. Their study concluded that nanofluids improve heat transfer performance, with copper oxide-water nanofluid exhibiting superior thermal characteristics. Gupta et al. [3] conducted research on the thermal performance optimisation of heat pipes using nanofluids and reported a collector efficiency of 66.40% at a nanofluid concentration of 1.1% and at an inclination angle of 58.5°C. Alqdah et al. [4] investigated the design, fabrication and performance evaluation of a shell-and-tube heat exchanger integrated with an evacuated tube solar collector. Their findings indicated that the system was reliable and effective for evaluating thermal performance under varying operating conditions such as solar radiation intensity, ambient temperature and inclination angle. Shafieian et al. [5] studied the thermal performance of evacuated tube heat pipe solar water heating systems during cold seasons. They concluded that additional thermal enhancement techniques are required during morning hours to improve solar energy absorption. Eidan et al. [6] experimentally investigated the performance of heat pipe evacuated tube collectors using Al_2O_3 and CuO nanofluids. Their results demonstrated that CuO nanofluid significantly improved thermal efficiency and accelerated temperature rise. Kim et al. [7] reviewed the thermal performance and efficiency of evacuated tube solar collectors using various nanofluids and conducted CFD analysis of heat pipe solar water heaters. Their study confirmed that nanofluids considerably enhance thermal performance. Putra et al. [8] analysed the thermal performance of evacuated tube heat pipe solar collectors and concluded that both vacuum conditions and nanofluid properties are critical factors affecting collector efficiency. They also reported that thermosyphon evacuated tube collectors perform better than conventional heat pipe collectors. Joo et al. [9] experimentally analysed the effect of different working fluids, including water, ethanol, Flutec and methyl acetate, on evacuated tube solar collector performance. Their results indicated that methyl acetate provided the best performance at an inclination angle of 40°. Lopez et al. [10] investigated the thermo-hydraulic performance and entropy generation characteristics of evacuated tube solar collectors using pure water and nanofluids as working fluids. Mahendran et al. [11] studied the thermal efficiency enhancement of direct-flow evacuated tube solar collectors using titanium oxide nanofluids. Khalipe et al. [12] experimentally evaluated two-phase closed thermosyphon evacuated tube solar collectors with different nanofluids. Sakhrieh et al. [13] investigated the performance of five types of solar collectors and reported that evacuated tubes with black coatings exhibited the highest efficiency. Chaudhari et al. [14] experimentally analysed a heat pipe heat exchanger using zinc oxide nanofluid dispersed in water and observed that the heat transfer coefficient increased with temperature. Gupta et al. [15] studied evacuated tube collectors at different mass flow rates and concluded that the thermal system size could be reduced by nearly 30%. Sarr et al. [16] determined the optimum tilt angle for photovoltaic modules in Senegal and recommended monthly adjustment of the tilt angle for improved solar energy conversion. Mahendran et al. [17] investigated the variation of global solar radiation in East Coast Malaysia. Chakraborty et al. [18] reviewed the stability characteristics of nanofluids under varying temperature, pressure, magnetic field, and heat transfer conditions. Alabayechi et al. [19] performed numerical and thermal simulations using STAR-CCM+ software and reported that aluminium oxide nanofluids increased water temperature. Aggarwal et al. [20] reviewed energy storage media and hybrid enhancement techniques for improving evacuated tube collector performance. Yazdi et al. [21] studied nanofluid flow inside evacuated tube solar collectors and concluded that the collector efficiency increases with increasing nanofluid volume fraction.

Tang et al. [22] investigated the effect of collector tilt angle and observed similar efficiencies at 22° and 46° inclination angles. Sundar et al. [23] experimentally studied Al_2O_3 nanofluids in ethylene glycol-water mixtures and reported that the thermal conductivity increased with nano-particle concentration but decreased with increasing temperature. Morrison et al. [24] developed a numerical model for heat transfer and fluid flow inside single-ended evacuated tubes and concluded that separate correlations are necessary for accurate flow rate prediction. Sukarno et al. [25] discussed challenges associated with nanofluid applications, including thermo-physical property determination, heat transfer behaviour and stability issues. Wole-Osho et al. [26] reviewed the limitations of nanofluids in solar thermal collectors and highlighted the need for further research on stability, hysteresis and long-term predictability. Ersöz et al. [27] investigated the influence of different working fluids on the energy and exergy performance of evacuated tube solar collectors with thermo-syphon heat pipes. Among the tested fluids – hexane, petroleum ether, chloroform, acetone, methanol and ethanol – acetone and chloroform demonstrated the highest exergy efficiency.

Although significant progress has been made in heat pipe solar collector technology, research on evacuated tube collectors using nanofluids as working fluids remains limited. Experimental and numerical investigations involving different working fluids are still required to determine optimal operating conditions. Most previous studies focused primarily on solar radiation effects; however, the integration of heat pipes and nanofluids can substantially enhance thermal energy absorption.

The vapour generated inside the heat pipe moves toward the condenser section, where heat is transferred to the manifold before the condensed liquid returns to the evaporator section, completing the continuous cycle. The performance of heat pipes is strongly influenced by parameters such as the inclination angle, solar radiation intensity and nanofluid concentration. Existing results indicate that copper oxide nanofluid is an effective working fluid for heat pipe applications. The present study utilises four evacuated tubes integrated with heat pipes, and it is anticipated that increasing the number of tubes and heat pipes will further improve the outlet water temperature and overall system efficiency.

2. Materials and methods

Nanoparticles consisting of nanometre-sized additives exhibit thermal properties, including the thermal conductivity, thermal diffusivity, viscosity and convective heat transfer coefficient, which differ from those of base fluids like water. Nanofluids are two-phase systems with phase one (liquid phase) and phase two (solid phase). The step method is used to prepare nanofluids. In this method, the first step produces dry powder by a chemical or physical method. Due to the trouble in making stable nanofluids by the two-step method, many progressive techniques have been developed to produce nanofluids. Copper oxide nanoparticles are manufactured at Adnano Technologies Pvt. Ltd., Shimoga, India, by the chemical precipitation method with multiple quality checks to obtain pure copper oxide nano-powder dispersed in water, as shown in Table 1.

Copper oxide nano-powder has an increased toughness and ductility, and an increased hardness. SEM and XRD techniques were used for analysis, as shown in Figs. 1 and 2. A graph of particle size distribution is presented in Fig. 2. A particle distribution indicates the percentage of particles of different size.

Table 1. Properties of nanofluid used in research work.

CuO	Description
Weight per cent	1%, 3%, 5% (wt.)
Particle size	30–70 nm
Physical form	liquid
Morphology of dispersed particle	Near spherical
Colour purity	Brownish black 99.5%

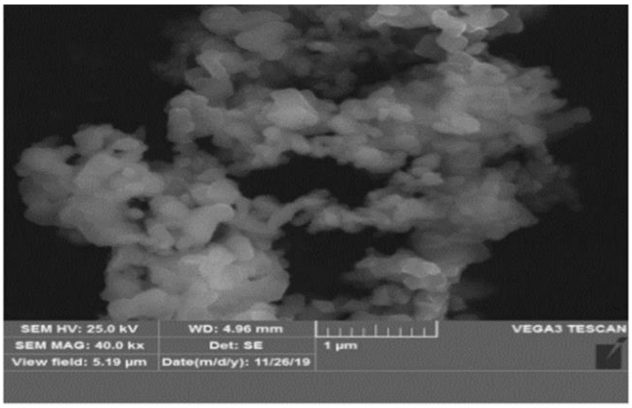

Fig. 1. SEM image of nanofluid.

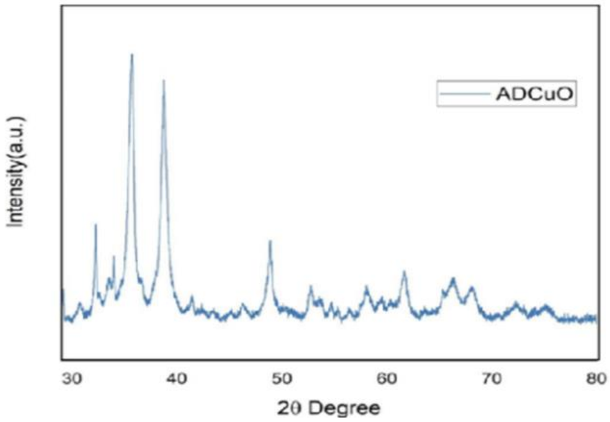

Fig. 2. XRD image of nanofluid.

The nanofluid was prepared by dispersing copper oxide with distilled water as a base fluid and filled in a heat pipe by weight per cent. The material used to prepare a heat pipe is copper. One end of the tube is well closed while the tube is vacuumed and charged with nanofluid from the other end, using a closing and opening mechanism, as shown in Fig. 3.

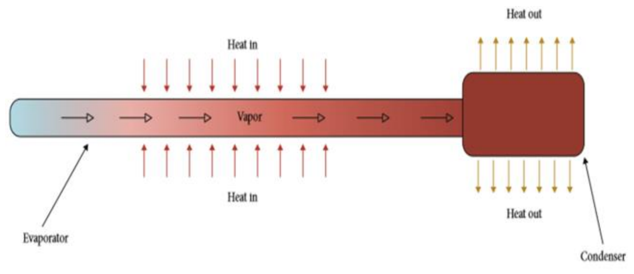

Fig. 3. Schematic diagram of the heat pipe.

During the experimentation, each of the copper tubes and evacuated tubes will be arranged in a tilted position and tested in outdoor conditions, but we are waiting for full sunshine hours for solar radiation. Monthly solar radiation at the location of Pune, India, for experimentation (longitude 74.15°, latitude 18.6°) is shown in Table 2. The water is taken as the working fluid and recirculated with the help of a pump. The heat pipe consists of three parts, which are the evaporator, the adiabatic part, and the condenser, as shown in Fig. 3. The working fluid inside the heat pipe evaporates as a result of transferring thermal energy to its surface, and the vapour moves upwards towards the condenser part, as shown in Fig. 4. The temperature was measured using K-type thermocouples positioned as shown in Fig. 5. Four temperature sensors were used to measure the temperature at the heat pipe condenser section, while one sensor was placed to measure the inlet temperature of water, and another was placed to measure the outlet temperature of water.

Table 2. Monthly solar radiation.

Month	Sunshine hours	Day length, hours
Jan	8.7	11.15
Feb	8.9	11.53
March	9.0	12.02
April	9.7	12.55
May	9.6	12.99
Oct	7.8	11.72
Nov	8.3	11.27
Dec	8.4	11.03

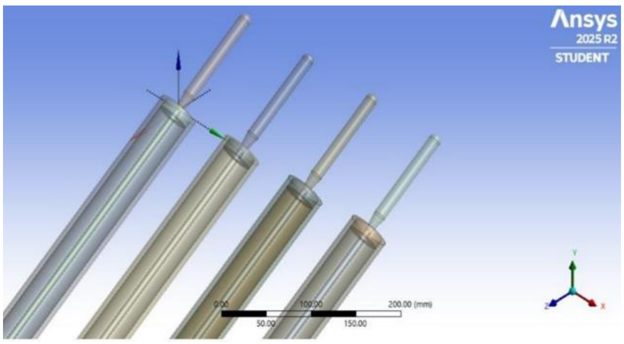

Fig. 4. Assembly of heat pipes with evacuated tubes.

Four evacuated tubes are installed as shown in Fig. 5. Heat pipes are filled with copper oxide nanofluid dispersed in deionised (DI) water to absorb solar energy. Solar energy is transferred to the recirculating water in the header of the condenser section of the heat pipe, and the recirculating water absorbs thermal energy from the condenser section of the heat pipe, completing the cycle.

Fig. 5. Experimental setup of evacuated tube solar collector.

Throughout the test, the ambient temperature, inlet water temperature, outlet water temperature and heat pipe condenser temperature were recorded. The mass flow rate at the inlet of the header is controlled by a rotameter. The temperature of heat pipes and recirculating water was measured by thermocouples placed as shown in the figure. The solar system consists of evacuated tubes, copper pipes, a tank with a circulation pipe, and a suitable frame for mounting. There are four copper tubes installed with some inclination, as shown in Fig. 5. These copper tubes are surrounded by borosilicate glass tubes. The inlet pipe is connected to the header, and tubes are press-fitted in the header. Another thermocouple was placed inside the storage tank. Water was circulated through the header. During the experimentation, each of the copper tubes and evacuated tubes will be arranged in a tilted position and tested in outdoor conditions.

The rate of useful solar energy (Q_u) is calculated by:

$$Q_u = M_w C_p (T_{out} - T_{in}), \tag{1}$$

where M_w is the mass of water and C_p is the specific heat of water, T_{out} is the outlet temperature of water, and T_{in} is the inlet temperature of water.

The incident solar radiation on the evacuated tube collector, which can be considered as input energy (Q_{in}), so the thermal efficiency of the system can be found as:

$$\eta = Q_u / Q_{in}. \tag{2}$$

3. Results and discussion

During the experimentation, each of the copper tubes and evacuated tubes was arranged in a tilted position and tested in outdoor conditions. The temperatures in the heat pipe condenser are gathered in Table 3, where $T1$ is the temperature at heat pipe 1, $T2$ is the temperature at heat pipe 2, $T3$ is the temperature at heat pipe 3, and $T4$ is the temperature at heat pipe 4.

Table 3. Temperatures at the heat pipe condenser.

T1 (°C)	*T2* (°C)	*T3* (°C)	*T4* (°C)
105	104	102	97
105	105	96	97
106	104	102	97
107	106	105	98
104	110	90	92
103	97	87	90

The graphs of inlet temperature, inclination angle of 40° to the ground level and outlet temperature captured throughout the day at full sunshine hours for different nanofluid concentrations are plotted in Figs. 6−8.

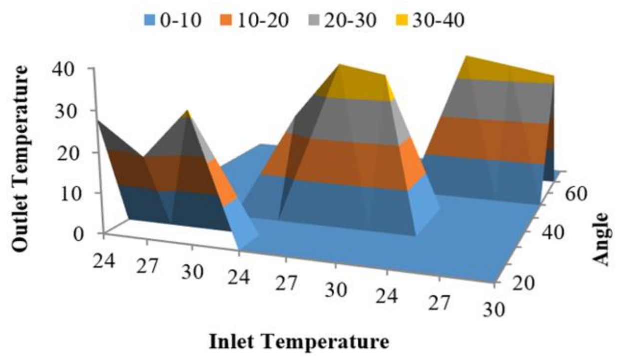

Fig. 6. Variation of temperature with tilt angle for 1% copper oxide nanofluid used in the heat pipe.

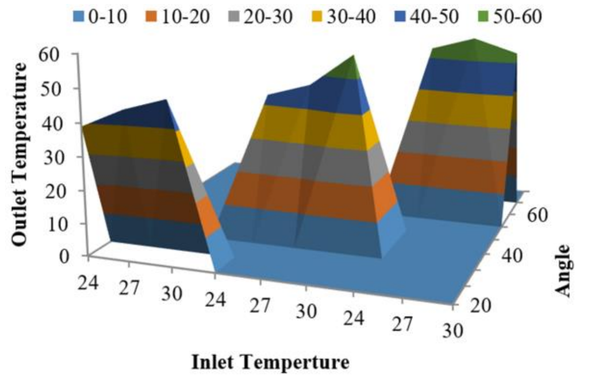

Fig. 7. Variation of temperature with tilt angle for 3% copper oxide nanofluid used in the heat pipe.

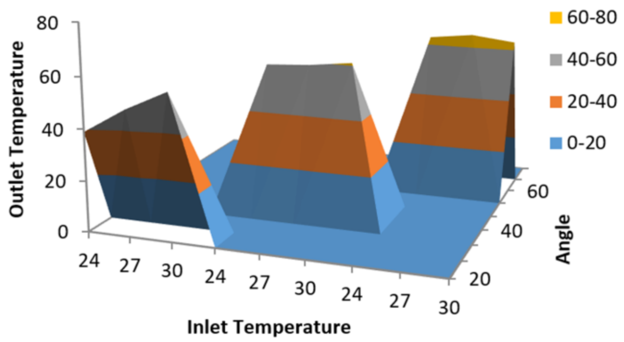

Fig. 8. Variation of temperature with tilt angle for 5% copper oxide nanofluid used in the heat pipe.

Based on the literature, the authors have decided to determine the variation of angle, copper oxide percentage, and inlet temperature in three levels taken for testing. Taugchi's robust design method was used with three parameters and three variable levels to cover a wide range. The control factors and levels (V1−V3 and L1−L3) are listed in Table 4.

A total of 27 experiments were conducted with three levels and three factors. For the experimental data set, ANOVA analysis was carried out for the prediction of the quality of the data.

Table 4. Control factors and levels.

Variable	Parameter	L1	L2	L3
V1	Angle (°)	20	40	60
V2	CuO (%)	1	3	5
V3	Inlet temperature (°C)	24	27	30

Table 5 shows the details for the analysis of variance (DF, SS, MS, F and P) for the outlet temperature. From the above table, it has been observed that p measure values for all the input parameters, such as the angle of tilt in degrees, copper oxide percentage, and input temperature, are less than 0.05. Hence, all these input parameters are identified as significant factors.

Table 5. Analysis of variance for outlet temperature.

Source	DF	SS	MS	F	P
Angle (°)	2	758.0	379.000	46.28	0.000
CuO (%)	2	816.7	408.333	49.86	0.000
Inlet temperature (°C)	2	356.2	178.111	21.75	0.000
Error	20	163.8	8.189		
Total	26	2094.7			

In the present experimentation, the optimum value of the angle in degrees is 40°, the optimum value of the copper percentage is 5 percent, and the input temperature is 30°C, as shown in Table 6.

Table 6. Optimum parameters.

Factors	Optimum values
Angle (°)	40
CuO (%)	5
Inlet temperature (°C)	30

Previous studies regarding heat pipe solar water heating systems have focused on solar radiation only, but by using a heat pipe and nanofluid in the solar collector, more energy is absorbed. The vapours inside the heat pipe rise towards the condenser section, where they transfer their heat through the manifold and return to the evaporator section, and the cycle continues. Heat pipe characteristics are dependent on the angle of inclination, solar radiation, and the percentage of nanofluid used. The above results show that copper oxide nanofluid is an effective working fluid for the heat pipe.

The present work is carried out with four evacuated tubes and heat pipes. If more tubes and a heat pipe are used, the outlet temperature will further increase, thereby resulting in the economics of material/price to heat capture. From the above result, the maximum outlet temperature is found to be about 68°C as shown in Table 7.

Table 7. Comparison of S/N ratio.

	Output temperature (°C)	S/N ratio
Predicted	66.6	36.70
Confirmed	68.0	36.65

The developed experimental setup in this work well predicts the increase in outlet temperature. As the performance of the heat pipe depends on the temperature of the evaporator and condenser area, more experimental and numerical work is required to explore the interaction effect among all the parameters of the evacuated tube heat pipe by using a nanofluid. Among the challenges for future research work are nanofluid preparation, in particular concerning the particle size, nanofluid stability, thermal conductivity and morphology.

4. Conclusions

The overall performance of the evacuated-tube solar collector was calculated. The outlet temperature was observed to vary with input parameters like the angle of inclination, CuO nanofluid concentration (% vol), and water inlet temperature. The outlet temperature was found to depend on the incoming solar radiation and the number of tubes, and the intensity of solar heat absorption was increased with the use of CuO nanofluid. The ANOVA analysis was carried out for the prediction of the quality of the data. The p-measure values for all input parameters, such as tilt angle, copper oxide percentage, and input temperature, were found to be less than 0.05, indicating a good level of significance. The best results for the water outlet temperature of 68°C were obtained for a 40° angle of inclination, 5% copper oxide nanofluid dispersed in distilled water, and 30°C of water inlet temperature. An increased concentration of CuO can be considered, however the possibility of contamination and fouling effects needs to be explored.

References

[1] Elbrashy, A., Aboutaleb, F., El-Fakharany, M., & Essa, F.A. (2023). Experimental study of solar air heater performance with evacuated tubes connected in series and involving nano-copper oxide/paraffin wax as thermal storage enhancer. *Environmental Science and Pollution Research*, 30(2), 4603−4616. doi: 10.1007/s11356-022-22462-6

[2] Yurddaş, A. (2020). Optimization and thermal performance of evacuated tube solar collector with various nanofluids. *International Journal of Heat and Mass Transfer*, 152, 119496. doi: 10.1016/j.ijheatmasstransfer.2020.119496

[3] Gupta, N.K., Sharma, A., Rathore, P.K.S., & Verma, S.K. (2020). Thermal performance optimization of heat pipe using nanofluid: response surface methodology. *Journal of the Brazilian Society of Mechanical Sciences and Engineering*. 42(11), 590. doi: 10.1007/s40430-020-02668-w

[4] Alqdah, K.S., Alfredi, A., Alnuman, N., Aljohani, M., Almutairi, M., & Alhazmi, A. (2020). Design, Fabrication and Testing of Shell and Tube Heat Exchanger Integrated with Vacuum Tubes Solar Water Heater. *Journal of Energy Research and Reviews*, 6(3), 1−16. doi: 10.9734/jenrr/2020/v6i330167

[5] Shafieian, A., Khiadani, M., & Nosrati, A. (2019). Thermal performance of an evacuated tube heat pipe solar water heating system in cold season. *Applied Thermal Engineering*, 149, 644−657. doi: 10.1016/j.applthermaleng.2018.12.078

[6] Eidan, A.A., AlSahlani, A., Ahmed, A.Q., Al-fahham, M., & Jalil, J.M. (2018). Improving the performance of heat pipe-evacuated tube solar collector experimentally by using Al_2O_3 and CuO/acetone nanofluids. *Solar Energy*, 173, 780−788. doi: 10.1016/j.solener.2018.08.013

[7] Kim, H., Kim, J., & Cho, H. (2017). Review of thermal performance and efficiency in evacuated tube solar collector with various nanofluids. *International Journal of Air-Conditioning and Refrigeration*, *25*(02), 1730001. doi: 10.1142/S2010132517300014

[8] Putra, N., Kristian, M.R., David, R., Haliansyah, K., & Ariantara, B. (2016). Thermal performance of evacuated tube heat pipe solar collector. In *AIP Conference Proceedings*, 1737(1), 050004. AIP Publishing LLC. doi: 10.1063/1.4949307

[9] Joo, H.J., & Kwak, H.Y. (2017). Experimental analysis of thermal performance according to heat pipe working fluids for evacuated tube solar collector. *Heat and Mass Transfer*, 53(11), 3267−3275. doi: 10.1007/s00231-017-2029-0

[10] López-Núñez, O.A., Lara, F., Gonzalez-Angeles, A., Cárdenas-Robles, A., Ramírez-Minguela, J.J., & Alfaro-Ayala, J.A. (2024). Assessment of thermohydraulic performance and entropy generation in an evacuated tube solar collector employing pure water and nanofluids as working fluids. *Heliyon*, 10(8), e29309. doi: 10.1016/j.heliyon.2024.e29309

[11] Mahendran, M., Ali, T.Z.S., Shahrani, A., & Bakar, R.A. (2014). The efficiency enhancement on the direct flow evacuated tube solar collector using water-based titanium oxide nanofluids. *Applied Mechanics and Materials*, 465, 308−315. doi: 10.4028/www.scientific.net/AMM.465-466.308

[12] Khalipe, V., & Deshmukh, P. (2015). Experimental study of evacuated tube two phase closed thermosyphon (TPCT) solar collector with nanofluid. *Journal of Mechanical and Civil Engineering (IOSRJMCE)*, 3(21), 156−161.

[13] Sakhrieh, A., & Al-Ghandoor, A. (2013). Experimental investigation of the performance of five types of solar collectors. *Energy Conversion and Management*, 65, 715−720. doi: 10.1016/j.enconman.2011.12.038

[14] Chaudhari, V., Dharmadhikari, M., & Kolhe, V. (2023). Performance Evaluation of Heat Pipe Heat Exchanger with Nanofluid: An Experimental Study. *Letters in Applied NanoBioScience*, 12(4), 121. doi: 10.33263/LIANBS124.121

[15] Gupta, M., Prasad, R.B., & Singh, A. (2023). Thermal Performance of Evacuated Tube Solar Collector using Water and CuO/Water Nanofluid. *AIJR Proceedings*, pp. 120−127. doi: 10.21467/proceedings.161.13

[16] Sarr, A., Kebe, C.M., & Ndiaye, A. (2021). Determination of the optimum tilt angle for photovoltaic modules in Senegal. *African Journal of Environmental Science and Technology*, 15(6), 214−222. doi: 10.5897/AJEST2021.2988

[17] Mahendran, M., Lee, G.C, Shahrani, A., Bakar, R.A., Kadirgama, K., Amir, A.R., & Sharma, K.V. (2013). Diurnal pattern and estimation of global solar radiation in East Coast Malaysia. *International Journal of Automotive and Mechanical Engineering*, 8, 1162−1175. doi: 10.15282/ijame.8.2013.7.0095

[18] Chakraborty, S., & Panigrahi, P.K. (2020). Stability of nanofluid: A review. *Applied Thermal Engineering*, 174, 115259. doi: 10.1016/j.applthermaleng.2020.115259

[19] Al-Abayechi, Y., Alaiwi, Y., & Al-Khafaji, Z. (2024). Exploration of Key Approaches to Enhance Evacuated Tube Solar Collector Efficiency. *Journal of Advanced Research in Numerical Heat Transfer*, 19(1), 1–14. doi: 10.37934/arnht.19.1.114

[20] Aggarwal, S., Kumar, R., Lee, D., Kumar, S., & Singh, T. (2023). A comprehensive review of techniques for increasing the efficiency of evacuated tube solar collectors. *Heliyon*, 9(4), e15185. doi: 10.1016/j.heliyon.2023.e15185

[21] Yazdi, M.H., Solomin, E., Fudholi, A., Divandari, G., & Sopian, K. (2021). Thermal Performance of Nanofluid Flow Inside Evacuated Tube Solar Collector. *International Journal of Heat & Technology*, 39(4), 1262–1270. doi: 10.18280/ijht.390424

[22] Tang, R., Yang, Y., & Gao, W. (2011). Comparative studies on thermal performance of water-in-glass evacuated tube solar water heaters with different collector tilt-angles. *Solar Energy*, 85(7), 1381−1389. doi: 10.1016/j.solener.2011.03.019

[23] Sundar, L.S., Ramana, E.V., Singh, M.K., & Sousa, A.C.M. (2014). Thermal conductivity and viscosity of stabilized ethylene glycol and water mixture Al2O3 nanofluids for heat transfer applications: An experimental study. *International Communications in Heat and Mass Transfer*, 56, 86−95. doi: 10.1016/j.icheatmasstransfer.2014.06.009

[24] Morrison, G.L., Budihardjo, I., & Behnia, M. (2005). Measurement and simulation of flow rate in a water-in-glass evacuated tube solar water heater. *Solar Energy*, 78(2), 257−267. doi: 10.1016/j.solener.2004.09.005

[25] Sukarno, D.H. (2017). Challenges for nanofluid applications in heat transfer technology. In *Journal of Physics: Conference Series*, 795(1), 012020. IOP Publishing. doi: 10.1088/1742-6596/795/1/012020

[26] Wole-Osho, I., Okonkwo, E.C., Abbasoglu, S., & Kavaz, D. (2020). Nanofluids in solar thermal collectors: review and limitations. *International Journal of Thermophysics*, 41, 157. doi: 10.1007/s10765-020-02737-1

[27] Ersöz, M.A. (2016). Effects of different working fluid use on the energy and exergy performance for evacuated tube solar collector with thermosyphon heat pipe. *Renewable Energy*, 96, 244−256. doi: 10.1016/j.renene.2016.04.058