Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 11, Special Issue 8, 2023
DOI (Journal): 10.37591/JoPC

http://engineeringjournals.stmjournals.in/index.php/JoPC/index

Research JoPC

Enhancing the Performance of Evacuated Tube Heat Pipe Solar Collector Using CuO Nanofluid

N. Jayanthi[1,2], M. Venkatesh[3,*], R. Suresh Kumar[4]

Abstract

Renewable energy is an important component of sustainable development technologies that meet current demands without risking future generations' ability to meet their own. Due to fast expanding energy consumption and environmental concerns, many international scholars are seeking an alternate approach to fulfill future energy demand. Due to its abundance and pure nature, solar energy appears to be the most enticing option in this case. Because of their ease of use, high conversion factors, and economic viability, solar thermal systems are currently the most common. The performance of solar thermal technology is influenced by factors such as nanofluids, solar radiation, collector tilt, and so on. The temperature of the various nanofluids employed determines the system's efficiency. As a result, in this situation, their performance analysis is more critical. The temperature of the various nanofluids employed determines the system's efficiency. A heat transfer mechanism is the heat pipe that receives heat from the sun through the radiation absorbed by the working fluids and transports it from one location to another using the vaporization and condensation process. In recent years, evacuated tube Heat pipe applications for solar collectors are numerous. Using distilled water, R134a, and CuO Nanofluid as working fluids in heat pipe, an experimental investigation is conducted in this study to determine the thermal efficiency of an Evacuated Tube Heat Pipe Solar Collector (ETHPSC). The copper tube used to create the heat pipe in ETHPSC has an outside width of 18 mm and a stretch of 1820 mm. The influence of input variables based on the thermal performance of the ETHPSC, such as temperature distribution and time, was examined, compared, and debated. The results show that using CuO Nanofluid instead of distilled water and R134a increases the Heat Pipe Solar Collector (HPSC's) effectiveness. The CFD analysis was carried out for the heat pipe in ETHPSC used similar to that of the experimental investigation and the result holds good with the experimental values.

Keywords: Solar Collector, Nanofluids, Transfer of Heat, Thermal Efficiency, Distilled Water, R134a.

*__Author for Correspondence__
M. Venkatesh

[1]Assistant Professor, Department of Physics, R.M.K. College of Engineering and Technology, Tiruvallur, Tamil Nadu, India
[2]Research Scholar, Department of Physics, Periyar University, Salem, Tamil Nadu, India
[3]Assistant Professor and Head, Department of Physics, K.S. Rangasamy College of Arts and Science (Autonomous), Tiruchengode, Tamil Nadu, India
[4]Professor, Department of Mechanical Engineering, R.M.K. Engineering College, Tiruvallur, India

Received Date: November 27, 2023
Accepted Date: January 05, 2024
Published Date: 27 March 2024

Citation: N. Jayanthi, M. Venkatesh, R. Suresh Kumar. Enhancing the Performance of Evacuated Tube Heat Pipe Solar Collector Using CuO Nanofluid. Journal of Polymer & Composites. 2023; 11(Special Issue 8): S393–S407

INTRODUCTION

We have access to the most abundant and cost-free source of solar energy. It reaches the surface of the planet as solar radiation, which needs to be collected in the right way. Solar energy is being promoted more because it is a non-conventional source. Solar energy can be produced in a number of ways, such as by using Photo Voltaic (PV) cells to produce electricity and solar collectors to produce heat. It can also be used to heat and cool buildings. In the realm of energy collection, various types of solar collectors are employed, with the Flat plate solar collector being the most prevalent. A flat plate solar collector's main disadvantage is its lower efficiency and higher thermal loss. This can be avoided by using evacuated tube solar collector. The main benefit of evacuated tube solar collectors (ETSC) is that they are more effective than other solar collectors and produce more surface temperatures. If the temperature rises over the boiling point of water, ETSC experiences issues. Because ETSC is made of annealed glasses, which are more delicate, it should be handled carefully while performing ETSC experiments investigated by Rassamakin et al. [1]. HPSC was used to get around the drawbacks of ETSCs and FPSCs. Azad [2] explored that the primary benefit is that they transfer thermal effect from tube surfaces to fluids with low heat resistance. Due to the phase transition it uses to transfer heat from liquid to vapour, HPSC has a higher efficiency compared to FPSCs and Evacuated Tube Solar Collectors (ETSCs). Ahmed Kadhim Hussein et al. [3] stated that neither condensation nor evaporation will take place above the temperature required for the liquid to vapour phase change so that the temperature inside the HPSC can be controlled.

According to Jayanthi et al. [4], connecting heat pipes to an evacuated tube solar collector can boost its heating efficiency (Figure 1). The Heat pipe has the benefit of transferring heat over a long distance. A heat pipe is the most effective heat transport device. An ETSC with a heat pipe offers a better thermal performance when compared to flat plate solar collectors. The apparatus uses an evaporator and a condenser component so that it can absorb solar energy in the evaporator and transmit heat as vapour to the condenser component investigated by Kang et al. [5]. The fundamental benefit of employing heat pipes is their high thermal conductivity and heat flux. Chan et al. [6] explored that the primary benefit of this heat transfer mechanism is the working fluids' ability to transfer from liquid phase to vapour phase throughout the evaporation and condensation stages. Solar collector performance was researched by Ayompe et al. [7] using ETSC and FPSC. Results indicate that for FPSC and ETSC, the thermal performance of the collector was 46% and 60.7%. Mustafa Ali Eroz [8] explored thermosyphon heat pipe ETSC. Abd-Elhady et al. [9] investigated how to improve the thermal efficiency of the evacuated tube heat pipe solar collector using oil and foamed metals. The findings showed that the rate of heat transmission increases by roughly 25%. Chopra et al. [10] used Evacuated tube solar collectors in experiments to test their thermal performance without and with heat pipes. Results explored that the Heat pipe with evacuated tube solar collectors shows maximum performance.

The evacuated tube comprises an absorber plate that a heat pipe is inserted into, as appeared in Figure 1. The absorber plate absorbs the solar radiation that strikes the evacuated glass tube, converting it to heat. In order to improve thermal efficiency, heat is transported from a heat pipe to domestic water passing via a heat exchanger called a "condenser." As a result, water tank that is insulated receives heat from the absorber tube. The condenser is encased in insulation and has a sheet metal or plastic cover to keep it safe. Inside the glass tube, a vacuum is generated, which considerably reduces convection loss. The working fluid used in the solar collector improves the efficiency of the device. Solar collector efficiency is raised by using nanofluids. Nanoparticles are small particles having an interfacial layer that range in size from 1 to 100 nanometers (nm). Dispersing nanometer-sized particles in base fluid produces nanofluids.

Solar collectors work on the basic premise of absorbing solar energy and using it to heat the typical fluid contained within the solar panel. The converted thermal energy from the solar collector is utilized in many ways. Suresh Kumar et al. [11] analyzed and reported on recent experiments that demonstrate the heat transmission properties of nanofluids in heat pipes in their study. Xue Fei Yang et al. [12] explained the Heat transfer performance of a horizontal micro-Grooved heat pipe using CuO nanofluid. Results showed that at operating pressure 7.45 KPa heat transfer improved by 46% and Heat flux enhanced by 30% by CuO nanofluid. Liu et al. [13] prepared copper oxide nanofluids by two step method. CuO nano particles were dispersed in ethylene glycol liquid. The experiment was concluded that low concentration of CuO nanofluids results in high thermal conductivity compared to base fluid ethylene glycol.

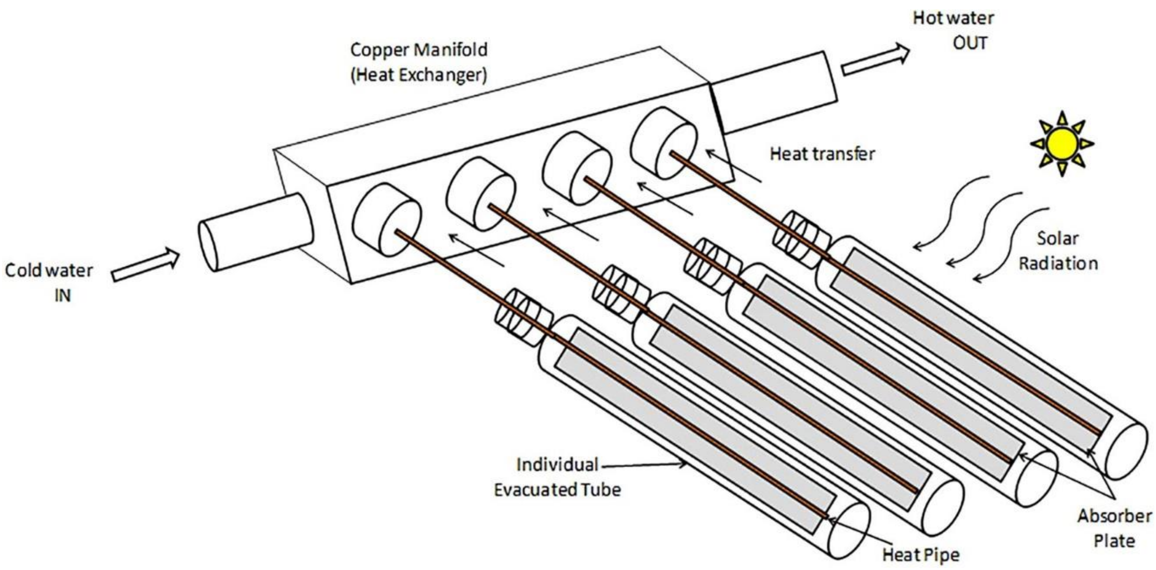


Figure 1. A schematic represent the evacuated tube heat pipe solar collector [4].

Using CuO nanofluid and water, Woobin et al. [14] examined the heat transmission capabilities of an evacuated tube solar collector. When CuO nanofluid used in an evacuated tube solar collector instead of water, CuO nanofluid can increase efficiency if it is maintained it under suitable operating conditions. The effectiveness of FPSC was evaluated by Ali Jabari Moghadam et al. [15] using the performance of a CuO/water nanofluid. According to the findings, each working fluid has a perfect mass flow rate that enhances collector effectiveness. In heat pipe solar collectors, the water-based CuO nanofluid flow was examined by Mohammad Shafiey Dehaj et al. [16]. He explored by using nanofluid thermal efficiency can be increased. Lu et al. [17] employed water- and Deionized-based CuO nanofluids for an evacuated tube solar air collector. CuO nanoparticles have been shown to increase the heat transfer coefficient by 30% while decreasing the wall temperature in an open thermosyphon. Sharafeldin et al. [18] used three different volume concentrations of CeO_2 nanoparticles: 0.015%, 0.025%, and 0.035%. The temperature difference between the input and output flow increases when nanofluids are used. The thermo-optical characteristics of a Evacuated tube solar corrector collector have been increased by 34%. Ali Jabari Moghadam et al. [15] made research in FPSC to determine the impact of CuO-water nanofluid. The average particle size is 40 nm, and the volume concentration of nanoparticles is 0.4%. The bulk flow rate of the working fluid varies between 1 and 3 kg/min. For a mass flow rate of 1 kg/min, the collector efficiency rises by roughly 21.8%. Results indicate that the thermal properties of nanoparticles with base fluid are improved. Additionally, it demonstrates that each working fluid has an optimal mass flow rate that enhances collector efficiency. Moghadassi et al. [19] explored the experiment based on the CuO nanoparticle size and CuO nanofluid concentration and the efficiency of ETSC utilizing CuO nanofluid was experimentally measured. The 40 nm-CuO nanofluid performed the solar collector at 69.1% of its potential. Thermal efficiency enhancement was 7.2% when 40 nm-CuO nanofluid was at its optimal concentration of 0.5 vol%. Mohammad Shafiey Dehaj et al. [20] utilized H_2O and Copper Oxide-H_2O nanofluid, the thermal performance of HPSC was examined. It was demonstrated that improving the volume % and mass flow rate of nanofluid enhanced the thermal performance of solar collectors. Tun-Ping Teng et al. [21] experimented thermal efficiency of heat pipe with Alumina Nanofluid. Thermal efficiency is 16.8% higher than distilled water when nanoparticles are at 0.1Wt%. Gabriela Huminic et al. [22] examined thermal performance of Thermosyphon heat pipe using iron oxide nanoparticles. Performance was improved by using iron oxide nanoparticles in water compared with DI-water. Rohini et al. [23] prepared CuO – water nanofluids by ultrasonication process by using Tiron dispersant. Results revealed that thermal conductivity improvement was obtained for CuO nanofluid at the percentage 13% and 44% at 28°C and 55°C respectively. Manimaran et al. [24] prepared copper oxide nanofluid by single –step wet chemical precipitation method. It is revealed that there is an enhancement in thermal conductivity for copper oxide nanofluid of about 12.4% compared to deionized water. Aberoumand et al. [25] investigated the Thermal conductivity of CuO nanoparticle dispersed in engine oil as base fluid was experimentally analyzed by the influence of volume concentration (0.2%, 0.5%, and 1%) and temperature. The experiment shows that thermal performance was increased to 49% for the 1% concentration of nanofluid compared to the base fluid. Li and Peterson et al [26] studied the effects of temperature and particle sizes of 36nm and 29nm on the thermal performance of Al_2O_3/H_2O and CuO /H_2O nanofluids were studied. Due to the change in temperature, thermal conductivity has increased for both nanofluids. Budak et al. [27] investigated Al_2O_3, CuO, and TiO_2 nanoparticles in distilled water at volume concentrations of 0.2, 0.4, and 0.8 to examine the effects of nanofluid. The results showed that nanofluid offers more effective collector than water. Sadeghi et al. [28] investigated by dispersing nanoparticle CuO in distilled water. The utilization of the nanofluid in ETSC in the volume fraction range of 0.01 to 0.08 was experimentally proven. The thermal efficiency of the ETSC's 0.08% volume fraction of nanofluid was improved. Liu et al. [29] prepared copper oxide nanofluids by two step method. CuO nano particles were dispersed in ethylene glycol liquid. The experiment was concluded that low concentration of CuO nanofluids results in high thermal conductivity compared to base fluid ethylene glycol.

Manoj Kumar et al. [30] studied the uses numerical analysis to examine the performance of a sintered wick heat pipe with a cylindrical shape in various orientations. The experimental data are used to compare and validate the outcomes. The investigation is expanded by employing a nanofluid as the working fluid, which contains nano-Curo in deionized water. The thermal performance of heat pipes using DI and nanofluid have been contrasted. NavidTonekaboni et al. [31] experimented a Solar Combined Cooling, Heating, and Power (SCCHP) system enhanced by nanofluid and porous media for the purpose of producing cooling, heating and electricity of a 600 m^2 building in a dry, warm region of Iran with mean solar radiation of Ib 820 W/m^2. The ideal amount of nanofluid to introduce into porous materials in order to prevent the formation of sediment has been estimated in this research. In this study, copper porous media with a 95% porosity and CuO and Al_2O_3 nanofluids were used to improve solar collectors.

In order to highlight recent advancements in machine learning research, Prabhakar Sharma et al. [32] evaluated the characteristics and uses of various machine learning algorithms used in the nanofluid-based renewable energy system. The merits and drawbacks of various contemporary machine learning techniques for nanofluid-based heat transfer research in renewable and sustainable energy systems were also discussed. Zafar Said et al. [33] used MWCNT + Fe_3O_4/Water hybrid Nanofluids to examine the performance of FPSC working in thermosyphon conditions. Various nanoparticle concentrations and Reynold's numbers were tested in the field. Thermal efficiency was improved by 63.84%. Zafar Said et al. [34] discovered that the performance of a STHX could be increased while using less energy and money overall when Multi-Wall Carbon Nanotubes (MWCNT) and water nanofluids were utilised. The stability and thermophysical characteristics of MWCNT/H_2O at volume fractions of 0.3% and 0.05% were studied. The investigations finally demonstrated the economic and environmental benefits of the solar-assisted STHX. Prabhakar Sharma et al. [35] explored Fe_3O_4-coated MWCNT hybrid Nanofluid thermophysical characteristics predictions. On statistical indices, the Artificial Intelligence (AI)-based Adaptive Neural Fuzzy Inference System (ANFIS) and Gene Expression Programming (GEP) models fared well. Taylor diagrams are used to validate and compare ANFIS and GEP-based prognostic models. The produced metamodel was sufficiently reliable to take the place of the time-consuming, expensive lab tests needed to quantify thermophysical parameters.

This work introduces the investigation of the impact of CuO nanofluid, R134a, and distilled water on the thermal performance of HPSC. The thermal efficiency of an evacuated tube heat pipe solar collector (ETHPSC) is investigated experimentally in this study using distilled water, R134a, and CuO Nanofluid as working fluids in heat pipe.

THEORETICAL INVESTIGATION

Numerical Analysis Using CFD (ANSYS R19.2)

Modeling

With a variety of working fluids, including distilled water, R134a, and CuO nanofluid, a CFD investigation of the heat pipe was conducted. The computational domain's geometry is modelled and meshed using the ANSYS R19.2. The analysis is conducted using ANSYS R19.2, a commercial CFD programme. Using CFD software, the numerical solution to the heat pipe's governing equation for fluid flow and heat transmission is derived.

The following boundary criteria are taken into account when analysing the heat pipes:

- Adiabatic-heat flux - 0 W/m^2
- Wall Face(Solid Zone) - Copper
- Vapour face(fluid zone) - Distilled water, R134a and CuO nanofluid.

Figure 2a and b depict the isometric view of the mesh-based three-dimensional heat pipe. Three zones make up the pipe wall's outside edge. While the condenser is subject to the convective boundary condition, the evaporator region has a heat flux boundary condition. Since the adiabatic zone in the middle of the heat pipe is insulated, the heat flux boundary condition with a value of zero is provided. The surface convective heat transfer coefficient on the condenser side, which is specified in the Computational Fluid Dynamics (CFD) analysis as 7 W/m^{2}K, is assessed using the correlation.

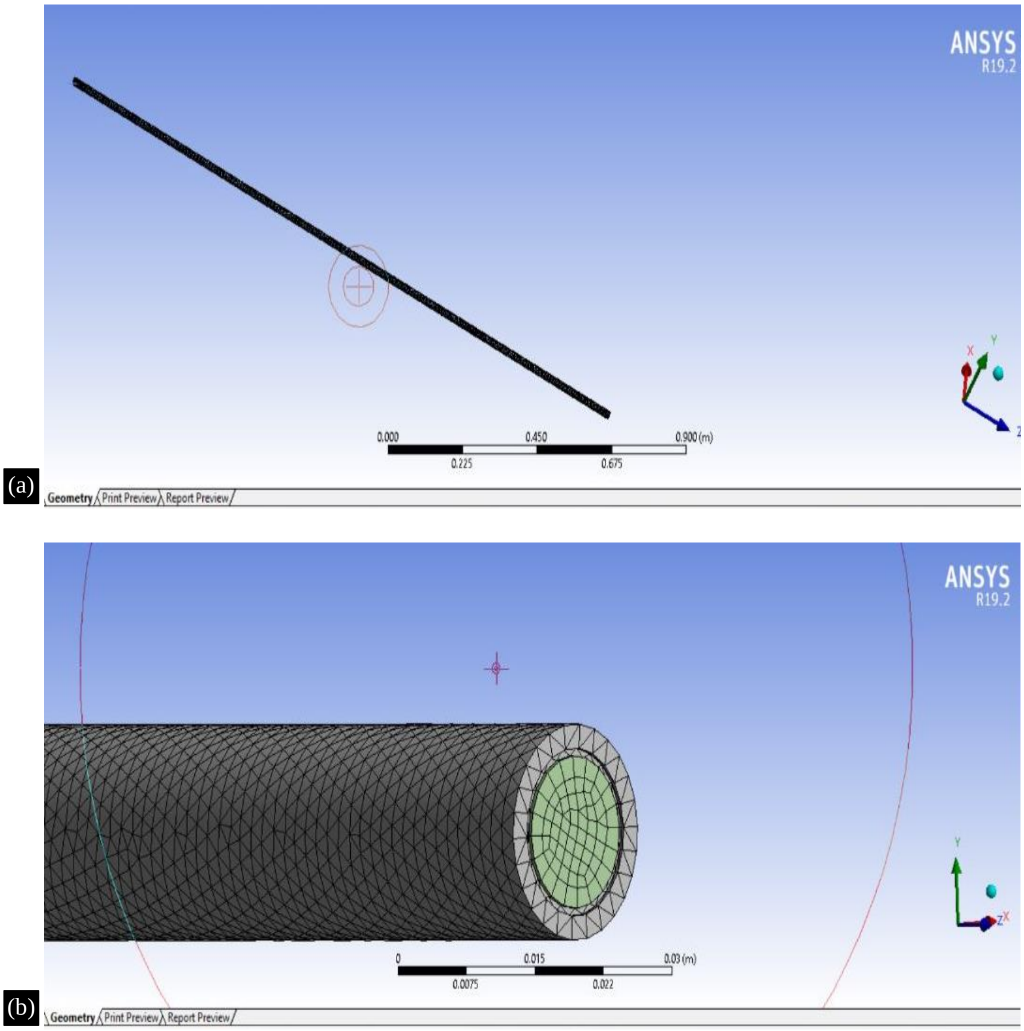


Figure 2. Schematic represents (a) Geometry and (b) Meshed model view in ANSYS R19.2 in 3D.

Meshing

Heat is transferred from the evaporator part to the condenser section using a heat pipe as a heat transfer device. ANSYS R19.2 software is used for modelling and meshing in 3D axis symmetry and Tetrahedral type of mesh is used in this study.

GRID INDEPENDENCE TEST:

In numerical simulations, a grid independence test assessed how the solution changes with different levels of mesh refinement.

The following steps are involved in the grid independence test:

1. *Mesh Generation:* Created multiple grids with varying levels of refinement (coarse, medium, fine) for the same simulation domain.
2. *Simulation Runs:* Performed simulations using the different grids generated in the previous step. The simulations were conducted with the same parameters and conditions across all grid resolutions.
3. *Result Analysis*: Analyzed the simulation results obtained from different grid densities.
4. *Selecting Optimal Mesh Resolution:* Based on the analysis, the mesh resolution for the solution becomes relatively independent of further grid refinement.

The grid independence test was conducted to ensure that the simulation results are reliable and not heavily influenced by the mesh density used. It helped in optimizing computational resources by using the minimum required mesh resolution without compromising the accuracy of the simulations.

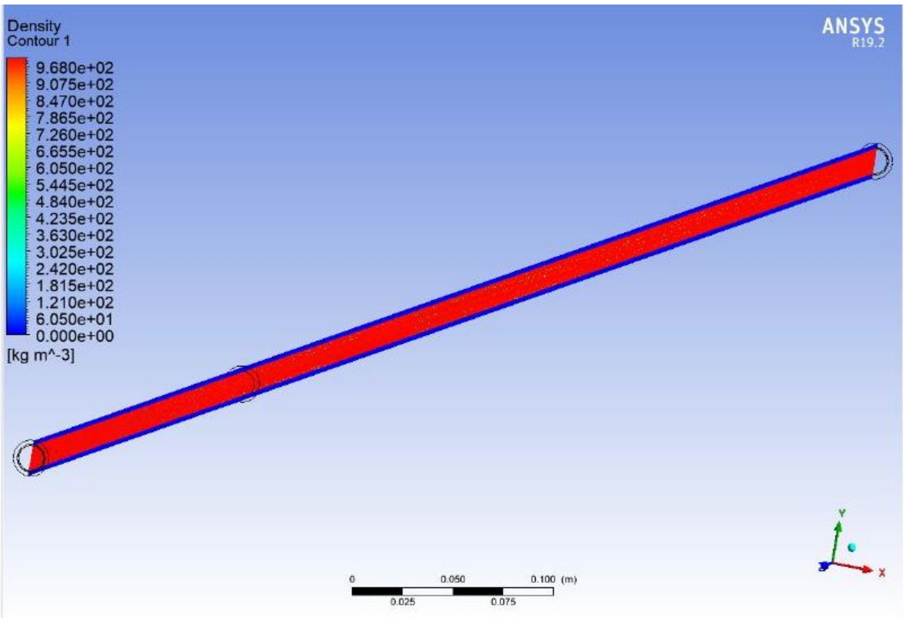
Simulation of Heat Pipe

In order to perform steady state pressure-based analysis, the meshed model is transferred to the commercial simulation program ANSYS R19.2, where the density and mass flow are recorded.

CFD Analysis of Thermosyphon Heat Pipe

Density, Mass flow and Pressure Contours of Heat Pipe

Experiments provide strong validation for the CFD analysis results. For the configurations employed for the experimental investigations, the CFD analysis was carried out. Figure 3 (a) to (c) display the findings of the CFD analysis for the heat pipe with the surface heat flux. The outcomes are in a fair amount of accord with those of the experimental inquiry. To expand the analysis to include more geometrical and dynamic parametric conditions, the CFD analysis will be helpful.



(a)

ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

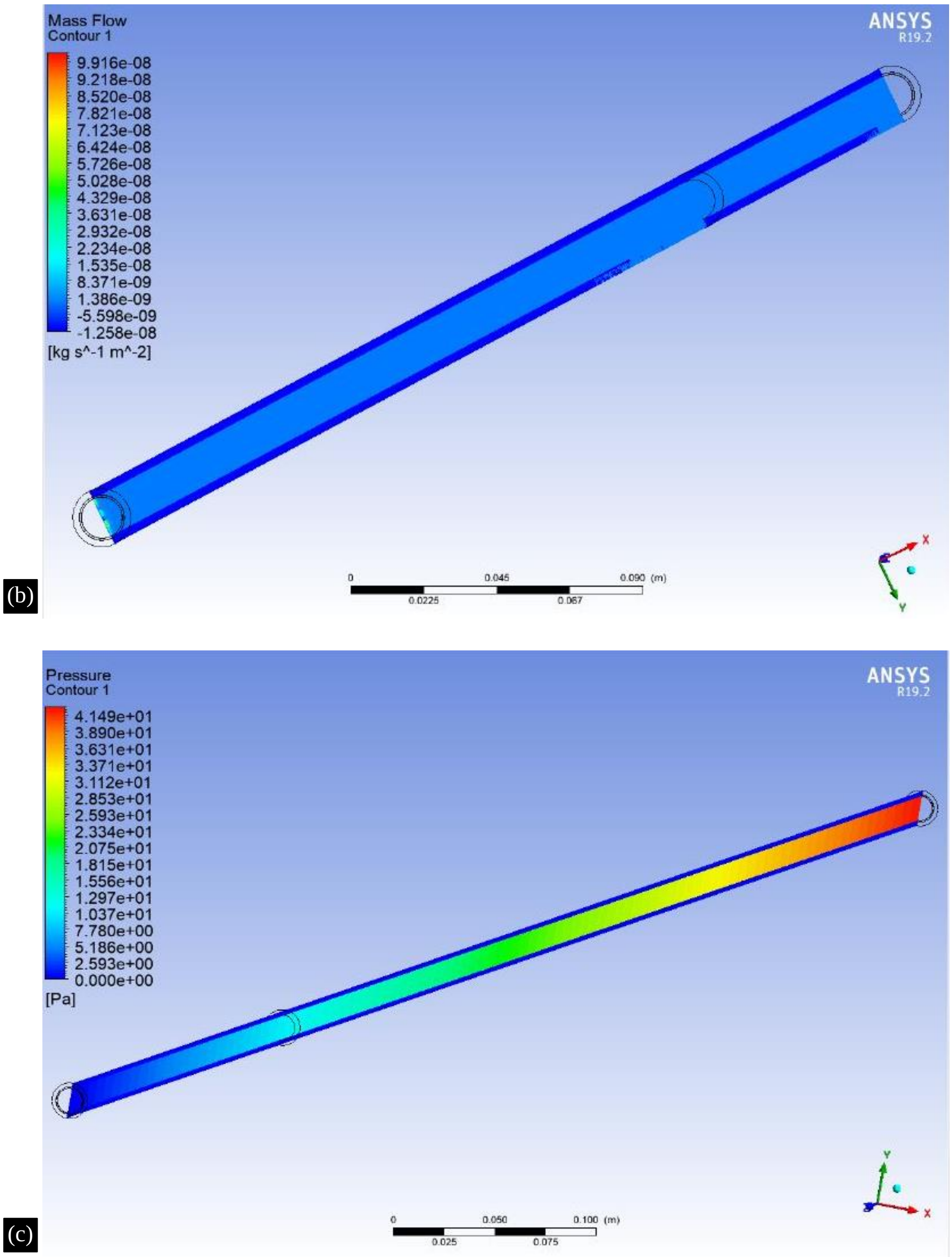


Figure 3. Schematic represents the (a) density,(b)mass flow and (c) pressure contours of heat pipe

Table 1. Properties of CuO nanoparticle.

Particle	Average diameter (nm)	Molecular weight	Density (g/mL) at 25°C	Surface area (m^2/g)
CuO	6–9 nm	79.55	6.31 g/cm^3	99.67

PREPARATION OF NANOFLUIDS

Hydrothermal technique was used to create CuO Nanoparticle. Nitric acid (HNO_3), sodium hydroxide, and copper (II) nitrate trihydrate were utilized as the starting precursors (NaOH). The combined solution's final pH value was adjusted to 8 using 2M NaOH and treated in a hydrothermal vessel at temperatures between 100 and 200°C for 4-6 hours. The dried material was obtained after being dried at 100°C for 5 hours. Properties of CuO nanoparticle was mentioned in Table 1. CuO Nanofluids were prepared by using ultrasonic homogenizer by using distilled water as a base fluid.

Experimental Investigation

The evacuated tube, heat pipe, condenser, Resistance Temperature Detector (RTD) sensor, working fluid, and stand were all needed pieces for the experimental setup as shown in Figurer 4 [36]. The header pipe was placed into the condenser section and sealed with a cap on the opposite end. The operating fluid to be filled in a third of its capacity, allowed for evaporation. Distilled water, R134a, and CuO nanofluids were the working fluids. These fluids were chosen for the study's objective of determining their efficacy. The heat from the header pipe was absorbed by the water flowing through the condenser. Evaporator, adiabatic, and condenser were the three sections that make up the heat pipe. The evaporator and condenser sections of the heat pipe were near the end. The working fluids (distilled water, R134a, and CuO Nanofluid) had been filled in heat pipe, and the end had been sealed. From 10:00 am to 3:00 pm, a reading was taken every hour. This technique was followed for each fluid. Using the RTD sensor, the temperature of the inlet and output water in the condenser was measured. For the calculation, the area's sun intensity was taken into account. Filling with refrigerant, the heat pipe had a hole on the bottom side. A heat pipe was a copper tube with a little amount of water within that was sealed on both ends. When heat was given to the pipe, the water boils and turns to vapour, which travelled to the heat pipe's condenser section and condenses back to a liquid. The water evaporates and condenses, creating a pumping action that moves the water along the pipe. A heat pipe's performance (the quantity of heat it can transfer)was further influenced by its length, diameter, wick structure, and general design. The more power that can be transmitted, the larger the pipe's diameter, but the longer the pipe's length, the less capable it was. Sintered heat pipes were superior than meshed heat pipes, which were superior to grooved heat pipes. Heat pipes can be twisted and flattened to move heat where it's needed or to fit into tighter places, but these changes reduce the amount of heat that can be transported. When the amount of heat to be transferred is too big for a single pipe, numerous pipes in parallel and series can be utilized to move more heat over longer distances.

A condenser was a device that transfers the heat pipe header's heat to the 15-liter input water capacity. To attach the heat pipe header, it contained four threaded holes. To prevent heat loss owing to convection, the condenser was insulated with glass wool. A temperature sensor was a device that measures temperature via an electrical signal, generally a thermocouple or RTD. A thermocouple (T/C) was a device composed of two metals that are different to one another and that generate an electrical voltage directly proportional to changes in temperature. An RTD was a type of variable resistor that reacts to temperature changes by changing its electrical resistance in a precise, repeatable, and nearly linear way. The platform was where the condenser was attached, and it contained four threaded holes for connected heat pipes. Through a hole in the lower part of the thermal pipe, refrigerant was injected. An evacuated tube's outer layer was utilized to prevent convective loss, while the inner layer was used to absorb solar radiation. Sunlight heat was captured by heat pipes, which then conveyed the heat to the working fluid. Phase change takes place as the working fluid's temperature increased, turning it from a liquid into a vapour. The working fluid moved toward the condenser due to capillary rise. The capillary rise of a liquid can be influenced by surface tension, the density of the liquid, the viscosity of the liquid and the presence of wick structure.

To determine the precise thermal characteristics of nanofluids, utilise the KD2 PRO-thermal property analyser. It is a battery-powered, menu-driven instrument for measuring viscosity, density, thermal conductivity, and specific heat capacity. The thermophysical properties are tabulated in Table 2.

Table 2. Thermo-physical properties of CuO nanofluid.

Nanofluid	Thermal Conductivity (W/mk)	Density kg/m^3	Specific heat (J/kg K)	Viscosity (Ns/m^2)
CuO+ H_2O	0.6666	1159.30	3586.64	8.9617×10^{-4}

ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

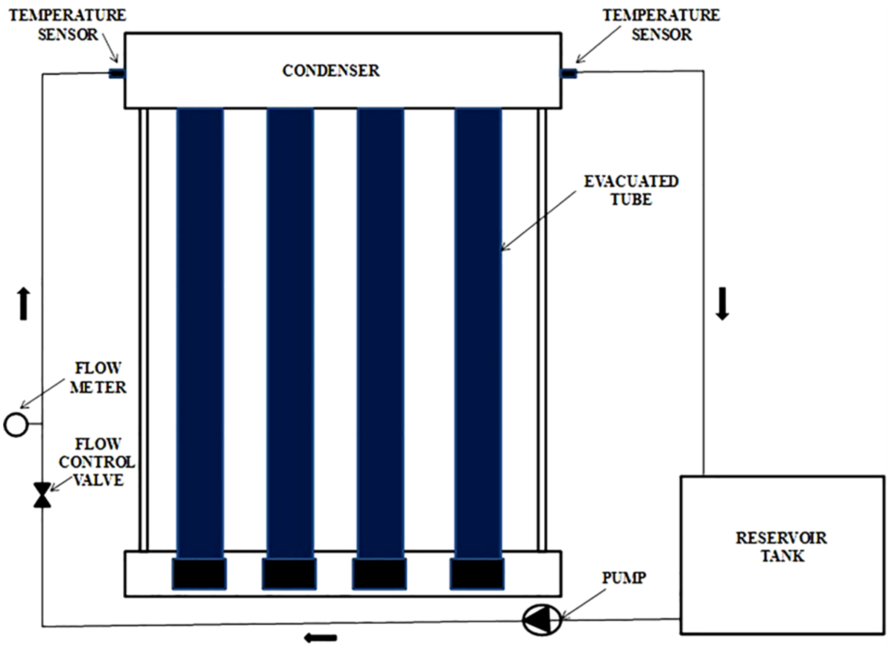


Figure 4. Sectional View of Experimental Setup [36].

In the condenser section, water will receive heat. The temperature that the water absorbs was equal to the temperature that the condenser loses. The working fluid's temperature will tends low until it enters the phase liquid, at which point it will descend with the aid of a wick. The mechanism regulated the processes of condensation and evaporation. Within a one-hour period, we tested the temperature difference between the intake and output. To get an efficiency difference between two fluids, the operation was repeated for both transfer fluid and a working fluid.

RESULTS AND DISCUSSION

Data Reduction

The following formula is used to calculate the collector's thermal efficiency,

$$\eta = \frac{\text{Gain in useful thermal energy}}{\text{Heat provided Qin}} = \text{Qu}/\text{Qin}$$

Where Heat provided can be found by using sun radiation level and collecting zone. Gain in useful thermal energy can be identified by Flow rate of water, unique water temperature and Differing temperatures.

The graph indicates that (Figure 5) the outflow temperature rises and reaches a maximum of 60 degrees Celsius between 10:30 am and 1:30 pm. The heat pipe solar collector receives the maximum solar energy around 1.30 PM due to the strong solar radiation. The graph (Figure 6) above depicts the variation in water outlet temperature for the working fluid R134a over time. From 10.30 am until 1.30 pm, the outlet temperature rises and reaches a high of 71 degrees Celsius. Due to R134a's high thermal stability and low boiling point, the heat pipe solar collector's water outlet temperature reached a high level around noontime at 1.30 PM.

The fluctuation in water outlet temperature when CuO nanofluid is utilized as the working fluid is shown in the graph above (Figure 7). At 1.30 p.m., the maximum outflow temperature was 78°C. When compared to R134a and distilled water, the outlet temperature of the Evacuated tube heat pipe solar collector was increased using CuO nanofluid. When compared to R134a and distilled water, the surface temperature range of CuO nanofluid appears to be greater. Convective heat transfer across the wall decreases as the surface temperature of the heat pipe containing the CuO nanofluid rises, but conductive heat transfer through the tube increases.

The collector thermal efficiency for three different working fluids is shown in the graph above (Figure 8) as a function of time. The ratio of useful heat energy gained to heat delivered can be used to calculate a collector's thermal efficiency. The efficiency was computed for various heat pipe temperatures, and the maximum efficiency was found at 1.30 pm. The thermal efficiency of a heat pipe solar collector containing CuO nanofluid was higher than R134a and distilled water, according to the results. In comparison to R134a and Distilled water, a heat pipe containing CuO nanofluid shows a maximum temperature of 86°C in the graph above (Figure 9). Because of the thermophysical features of CuO nanofluid, heat pipes containing nanofluid have a higher surface temperature, resulting in a higher maximum heat pipe temperature when compared to R134a and distilled water.

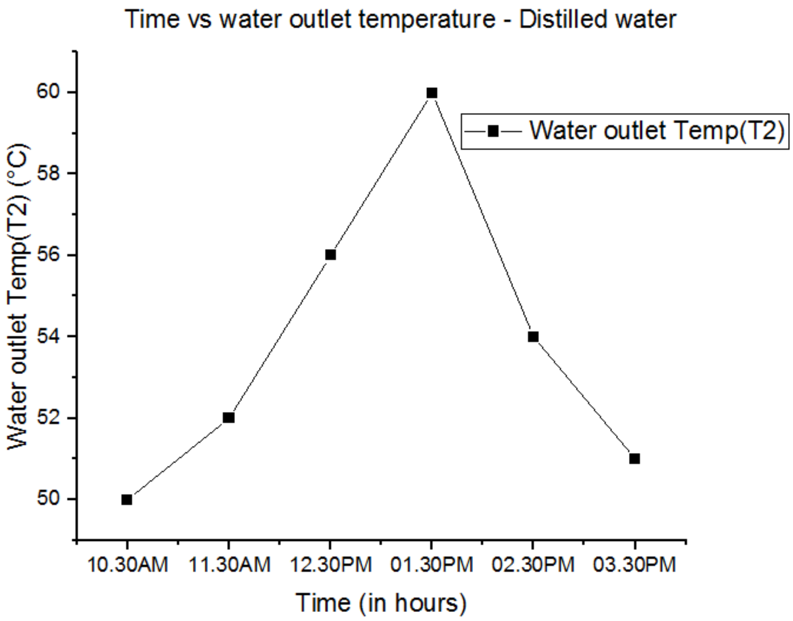


Figure 5. Variation of outlet water temperature with time (Working Fluid: distilled water).

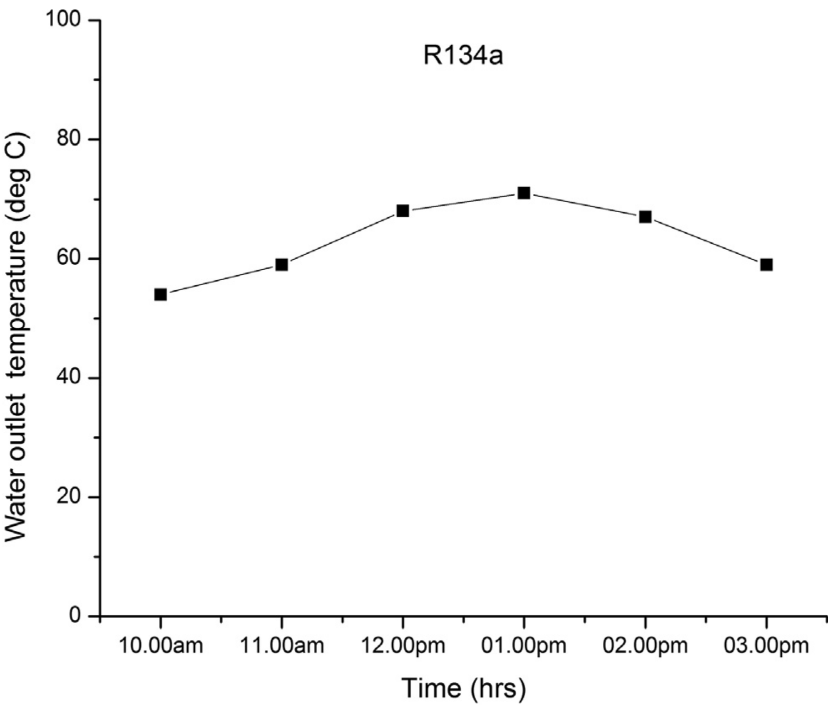


Figure 6. Variation of outlet water temperature with time (Working Fluid: R134a).

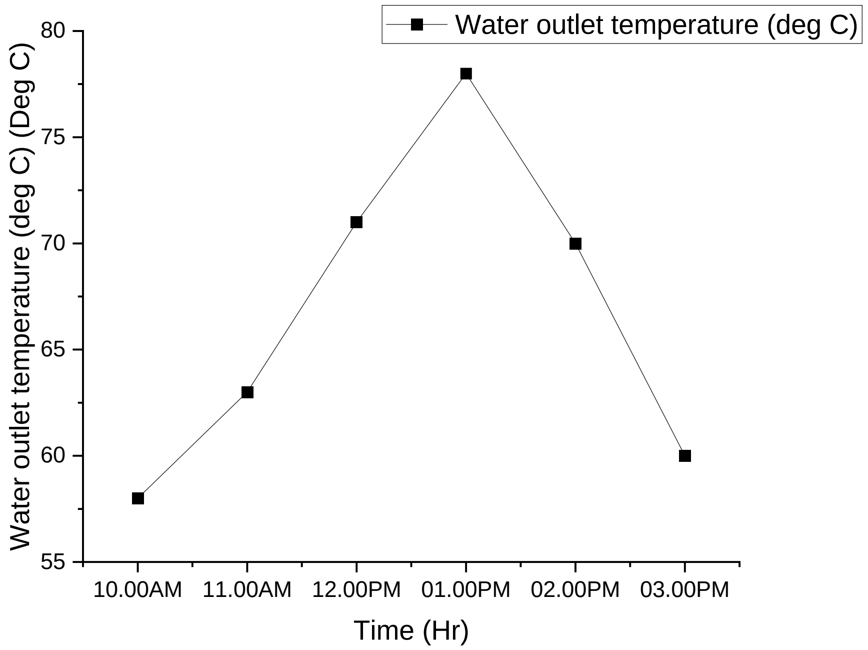


Figure 7. Output water temperature varies with time. (Working Fluid: CuO nanofluid).

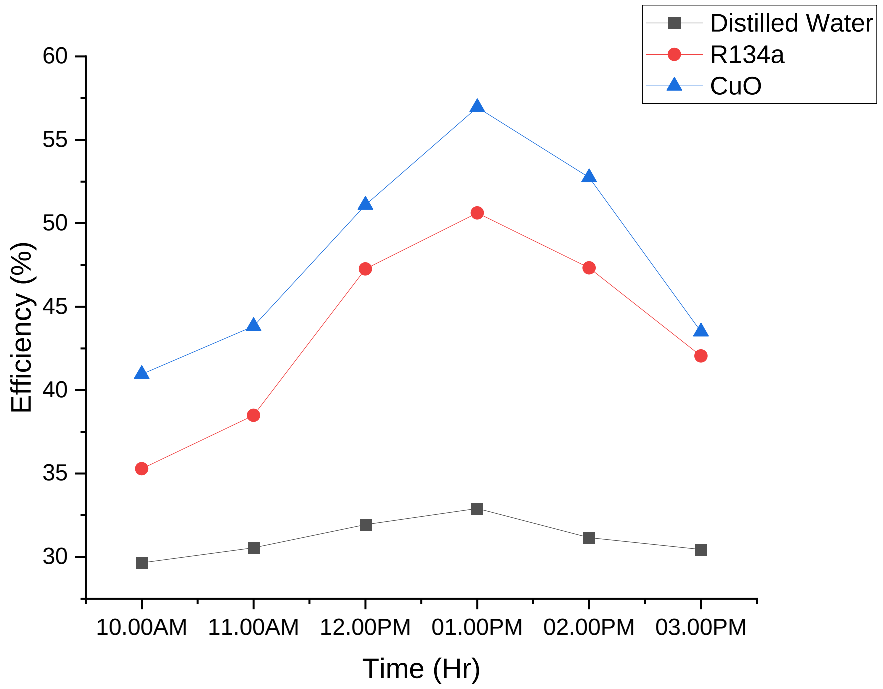


Figure 8. Comparison of collector thermal efficiency of working fluids with time.

Percentage increase in efficiency = (48.17–31.25)/(31.25)
Percentage increase in efficiency = 54.14%

Using nanofluid (CuO) as the working fluid, the extreme thermal performance is reached at 1.00 pm, as seen in the graph above (Figure 10). Compared to two other working fluids nanofluid (CuO) gives higher efficiency due to their thermophysical properties. From the percentage increase in efficiency, it is calculated as 54.14%. It shows that CuO nanofluid gives better efficiency compared to Distilled water, R134a.

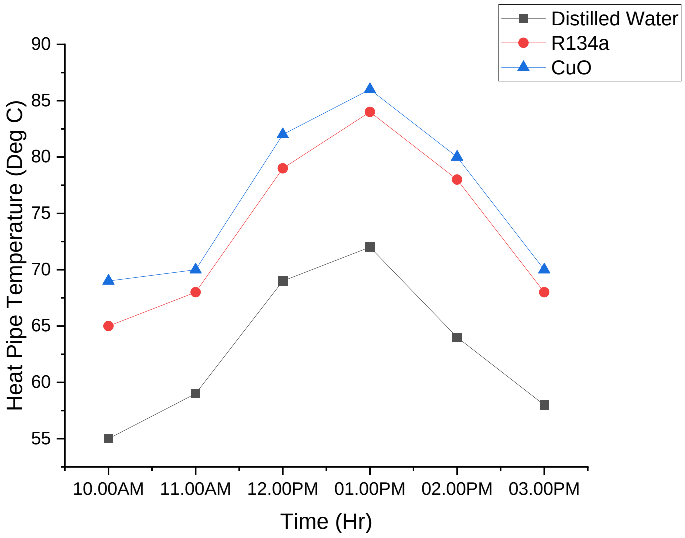


Figure 9. Comparison of heat pipe temperature of working fluid with time

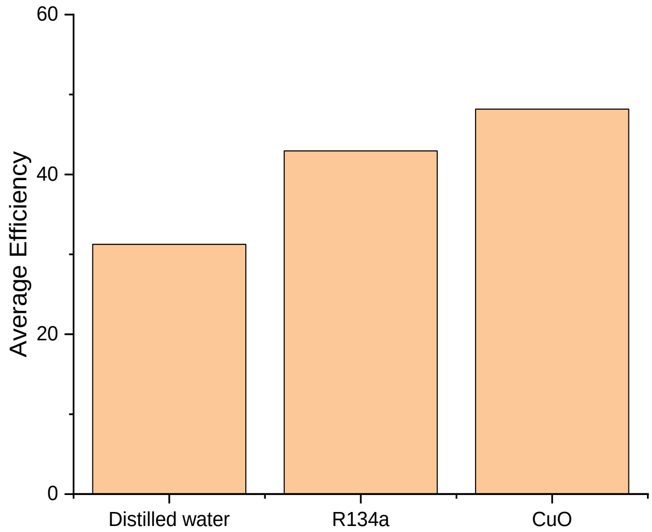


Figure 10. Comparison of average efficiency of working fluid.

CONCLUSION

ETHPSC's thermal performance was investigated experimentally using R134a, distilled water, and CuO nanofluid. The effect of various input factors of the ETHPSC was examined and contrasted.

The following findings are possible based on the experiments and analyses:

1. The efficiency enhancement obtained is 54.14%**.**
2. Experimental results showed that CuO nanofluid with heat pipe has more thermal efficiency.
3. It was discovered that the presence of metal oxide particles in the nanofluid increased the working fluid's conductivity and heat transfer rate.
4. The heat pipe in the ETHPSC was subjected to the CFD analysis in a manner comparable to that of the experimental research, and the outcome is consistent with the experimental values.
5. However, there are still a lot of difficulties and difficulties with the usage of nanofluids in real-world applications.
6. According to studies, using heat pipes with nanofluids as the working fluid has a favorable effect.
7. Evacuated Tube Heat pipe Solar Collector (ETHPSC) using nanofluid research is still in its development and has to be further upon.

Conflicts of Interest

"The authors declare that they have no conflicts of interest".

Authors' Contributions

"All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication".

Data Availability

"The raw data supporting the conclusions of this article will be made available by the corresponding author without undue reservation".

Funding

"There is no funding support for this study".

NOMENCLATURE

Abbreviations

PV-Photo Voltaic
ETSC-Evacuated Tube Solar Collector
FPSC-Flat Plate Solar Collector
HPSC-Heat Pipe Solar Collector
EPSC–Evacuated Pipe Solar Collector
ETHPSC-Evacuated Tube Heat Pipe Solar Collector
RTD-Resistance Temperature Detector
T/C–thermocouple
CFD-Computational Fluid Dynamics
MWCNT-Multi-Wall Carbon Nanotubes
STHX-Shell and Tube Heat Exchanger
AI-Artificial Intelligence
ANFIS-Adaptive Neural Fuzzy Inference System
GEP-Gene Expression Programming

SYMBOLS

Q_u-Useful heat energy gain
Q_{in}- Heat supplied
I_t –Solar radiation intensity (W/m^2)
A_c–Collector area (m^2)
m_f–Water mass flow rate (kg/s)
C_P–Specific heat of water(J/kgK)
ΔT–Temperature difference (°C)
D–Diameter of evacuated tube (m)
L–Length of the evacuated tube(m)
A_c–Area of the Collector (m^2)
η–Efficiency of ETHPSC, (%)

REFERENCES

1. Rassamakin B, Khairnasov S, Zaripov V, Rassamakin A, Alforova O. Aluminium heat pipes applied in solar collector.*SolEne.*2013;94:145–54p.
2. Azad E. Theoretical and experimental investigation of heat pipe solar collector. *Ther flu sci*. 2008; 32: 1666–72p.
3. Ahmed KadhimHussein,Dong Li.,Lioua Kolsi, Sanatana Kata. A review of nanofluid role to improve the performance of the heat pipe solar collectors. *EneProce*.2017;109 :417–424p.

4. Jayanthi N, Venkatesh M, Suresh Kumar R, Sekar S. A review on performance of nanofluids in various heat pipe solar collector. *Proc of the Inst of Mech Engg, Part: E Journal of process Mech Engg*.2021; 1–10p.
5. Kang S.W., Wei W.C., Tsai S.H., Huang C.C. Experimental investigation of nanofluids on sintered heat pipe thermal performance. *AppliThermEngg*. 2009; 29: 973–979p.
6. Chan C.W, Siqueiros E, Ling-Chin J, Royapoor M, Roskilly, A.P, Heat utilisation technologies: A critical review of heat pipes. *Rene Energy Revi*. 2015;50: 615–627p.
7. Ayompe L.M, Duffy A, McKeever M, Conlon M, McCormack S.J, Comparative field performance study of flat plate and heat pipe evacuated tube collectors (ETCs) for domestic water heating systems in a temperate climate. *Energy*.2011; 36: 3370–3378p.
8. Mustafa Ali Eroz. Effects of different working fluid use on the energy and exergy performance for evacuated tube solar collector with thermosyphon heat pipe. *Reneenergy*.2016; 96 : 244–256p.
9. Abd-Elhady M.S, Nasreldin M, Elsheikh M.N, Improving the performance of evacuated tube heat pipe collectors using oil and foamed metals. *Ain Shams Engg Journal*. 2019;9: 2683–268p.
10. Chopra K, Tyagi V.V, Pandey A.K, AhmetSari. Global advancement on experimental and thermal analysis of evacuated tube collector with and without heat pipe systems and possible applications. *Appl Energy*.2018; 228: 351–389p.
11. Sureshkumar R, TharvesMohideen S, Nethaji N, Heat transfer characteristics of nanofluids in heat pipes: A review.*Rene and Sustain Energy Revi*.2013;20:397–410p.
12. XueFei Yang, Zhen-Hua Liu, Jie Zhao. Heat transfer performance of a horizontal micro-grooved heat pipe using CuOnanofluid.*Jour of Micromechanics and Microengg*. 2008; 18: 1–6p.
13. Li Y., Zhou J., Tung S., Schneider E., Xi S. A review on development of nanofluid preparation and characterization. *Powder Tech.*2009;196: 89–101p.
14. Woobin Kang, Yunchan Shin &HonghyunChoin Kang, Experimental investigation on the heat transfer performance of evacuated tube solar collector using CuOnanofluid and water.Jour of MechSci and Tech.2019;33: 1477–1485p.
15. Mohammad ShafieyDehaj, MostafaZamaniMohiabadi, Experimental study of water-based CuOnanofluid flow in heat pipe solar collector. *Journ of ThermAnaly and Calorimetry*. 2019; 137, 2061–2072p.
16. Lin Lu, Zhen-Hua Liu, Hong-ShengXiao, Thermal performance of an open thermosyphon using nanofluids for high-temperature evacuated tubular solar collectors.*Sol Ene* :2011; 85: 379–387p.
17. M.A.Sharafeldin, GyulaGrof, Evacuated tube solar collector performance using CeO2/water nanofluid.*Jour of cleaner prod*; 2018:185 347–356p.
18. Ali JabariMoghadam, MahmoodFarzane-Gord, MahmoodSajadi, MonirehHoseyn-Zadeh, Effects of CuO/water nanofluid on the efficiency of a flat-plate solar collector.*ExpTherm fluid and Sci*.2014; 58:9–14p.
19. Moghadassi, A., Ghomi, E., Parvizian, F. A numerical study of water based $Al_2O_3$and Al_2O_3-Cu hybrid nanofluid effect on forced convective heat transfer. *Inter journal of ThermScie*. 2015;92: 50–57p.
20. Mohammad ShafieyDehaj, MostafaZamaniMohiabadi. Experimental study of water-based CuOnanofluid flow in heat pipe solar collector.*Journal of Therm Anal and Calori*. 2019;137:2061–2072p.
21. Tun-Ping Teng, How-GaoHsu, Huai-EnMo, Chien-Chih Chen. Thermal efficiency of heat pipe with alumina nanofluid.*Jour of Alloy and Comp*.2010; 504: S380–S384p.
22. Gabriela Huminic, Angel Huminic, Ion Morjan, Florian Dumitrache, Experimental study of the thermal performance of thermosyphon heat pipe using iron oxide nanoparticles. *Renew Ene*.2008; 115: 501-508p.
23. RohiniPriya K, Suganthi K S, Rajan K S, Transport properties of ultra-low concentration CuO–water nanofluids containing non-spherical nanoparticles, *Int. J. Heat Mass Transf*. 2012; 55 : 4734–4743p.

24. Manimaran R, PalaniradjaK,Alagumurthi N, Sendhilnathan S &Hussain J. Preparation and characterization of copper oxide nanofluid for heat transfer applications. 2014; 4: 163–167p.
25. Aberoumand S, Jafarimoghaddam A. Experimental study on synthesis, stability, thermal conductivity and viscosity of Cu–engine oil nanofluid. *Jour of Taiwan Inst of Chemical Engineers*.2017;71: 315–22p.
26. Li C.H, Peterson G P, Experimental investigation of temperature and volume fraction variations on the effective thermal conductivity of nanoparticle suspensions (nanofluids). *Journ of AppliPhy*. 2006;99: 1–8p.
27. BudakZiyadanogullari N, Yucel H L, Yildiz C. Thermal performance enhancement of flat-plate solar collectors by means of three different nanofluids. *ThermSci and Engg* Progress.2018; 8: 55‒65p.
28. Sadeghi G, Safarzadeh H, Ameri M. Experimental and numerical investigations on performance of evacuated tube solar collectors with parabolic concentrator, applying synthesized Cu2O/distilled water nanofluid. *Ene for Sust Develop*.2019; 48: 88‒106p.
29. Liu M S, Lin M C, Huang I T, Wang C C. Enhancement of Thermal Conductivity with CuO for Nanofluids. *Chem Engg and Tech*.2005; 29: 72‒77p.
30. ManojKumar P, Rajasekaran Saminathan, Mohammed Tharwan, HaithamHadidi P, Michael Joseph Stalin, Kumaresan G, Ram S, MotiLal Rinawa,. Saravana kumar P T, Karthikeyan K, and Dawit Tafesse Gebrey ohannes. Study on Sintered Wick Heat Pipe (SWHP) with CuO Nanofluids under Different Orientation. *Journal of Nanomaterials*.2021;1‒12P.
31. NavidTonekaboni, Mahdi Feizbahr, NimaTonekaboni, Guang-Jun Jiang, and Hong-Xia Chen. “Optimization of Solar CCHP Systems with Collector Enhanced by Porous Media and Nanofluid”, *Journal of Nanomaterials*.2021;1‒12p.
32. Prabhakar Sharma, Zafar Said, AnuragKumar,SandroNižetić, Ashok Pandey, Anh Tuan Hoang, Zuohua Huang, AsifAfzal, Changhe Li, Anh Tuan Le, Xuan Phuong Nguyen, and Viet Dung Tran.Recent Advances in Machine Learning Research for Nanofluid-Based Heat Transfer in Renewable Energy System. *Energy Fuels*;2022: 6626–6658p.
33. Zafar Said, Prabhakar Sharma, L.SyamSundar, Van Giao Nguyen, Viet Dung Tran and Van VangLe. Using Bayesian optimization and ensemble boosted regression trees for optimizing thermal performance of solar flat plate collector under thermosyphon condition employing MWCNT-Fe3O4/water hybrid Nanofluids. *Sustainable Energy Technologies and Assessments*. 2022; 53: 45‒48p.
34. Zafar Said, ShekRahman, Prabhakar Sharma, Ahmed Amine Hachicha, SalahIssa, “Performance characterization of a solar-powered shell and tube heat exchanger utilizing MWCNTs/water-based nanofluids: An experimental, numerical, and artificial intelligence approach. *Applied Thermal Engineering.* 2022; 212:312‒316p.
35. PrabhakarSharma,Zafar Said, SaimMemon, Rajvikram Madurai Elavarasan, Mohammad Khalid, Xuan Phuong Nguyen, MüslümArıcı, Anh Tuan Hoang, LanHuong Nguyen. Comparative evaluation of AI-based intelligent GEP and ANFIS models in prediction of thermophysical properties of Fe3O4-coated MWCNT hybrid nanofluids for potential application in energy systems. *International Journal of Energy Research*; 2022: 19242–19257p.
36. Jayanthi N, Suresh Kumar, Gopalu Karunakaran, Venkatesh M. Experimental investigation on the thermal performance of heat pipe solar collector (HPSC). *Mat Proceedings*.2020;26: 3569–3575p.