ENHANCEMENT AND EXPERIMENTAL STUDY ON THERMAL BEHAVIOUR OF HEAT PIPE BASED SOLAR ABSORBER BY USING CuO NANOFLUID

by

Mylswamy THIRUNAVUKKARASU[a], Kavitha SELVARAJ[b], Chalasani CHIRANJEEVI[c], Venkatesh RATHINAVELU[d*], Lakshmana Phaneendra MAGULURI[e], Sami Al OBAID[f], Sulaiman Ali ALHARBI[f], Md. Abul KALAM[g], and Ramadoss YOKESWARAN[h]

[a] Department of Automobile Engineering, Dr. Mahalingam College of Engineering and Technology, Coimbatore, Tamil Nadu, India
[b] Department of Mechanical Engineering, Kalasalingam Academy of Research and Education, Srivilliputhur, Virudhunagar, Tamil Nadu, India
[c] School of Mechanical Engineering, Vellore Institute of Technology, Vellore, Tamil Nadu, India
[d] Department of Mechanical Engineering, Saveetha School of Engineering, Saveetha Instituteof Medical and Technical Sciences (SIMATS), Tamilnadu, India
[e] Department of Computer Science and Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Andhra Pradesh, India
[f] Department of Botany and Microbiology, College of Science, King Saud University, Riyadh, Saudi Arabia
[g] School of Civil and Environmental Engineering, FEIT, University of Technology Sydney, NSW, Sydney, Australia
[h] Department of Mechanical Engineering, K. Ramakrishnan College of Technology, Tiruchirappalli, Tamilnadu, India

Original scientific paper
https://doi.org/10.2298/TSCI230311274T

Technological growth in thermal science found that the awareness of solar thermal energy improved widely in various applications and spotted issues on conventional flat plate solar collectors operating with water fluid: lower thermal efficiency, limited thermal performance during low sunlight, and unavoidable heat loss for extended plate surface. This research attempts to enhance the thermal performance of solar collectors modified with heat pipe solar absorber (HPSA) evaluated by 0.010, 0.015, and 0.02 volume fractions of CuO nanofluid at 18 Lpm. The effect of CuO on varied flow rate on temperature gain, heat transfer coefficient, and thermal efficiency of HPSA is experimentally studied, and its findings are compared with water fluid. The HPSA operates with 0.015 volume CuO nanofluid with a higher rate of flow, proving better thermal performance and offering a maximum temperature gain of 68 ºC with a better heat transfer coefficient of 81.5W/m^{2}K results enhanced thermal efficiency of 85.2%, which are higher than the water fluid operated HPSA system. An optimum operating parameter of HPSA is suggested for heat exchanger applications.

Key words: *CuO, heat pipe solar absorber, nanofluid, thermal performance*

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

Introduction

In a recent scenario, the energy gathered from renewable sourceswas significantly uptrend, and the contribution of renewable solar energy increased in different engineering applications [1]. The uniqueness of solar air heaters adopted for food, textile, space hating, and agricultural product drying applications [2-4]. With this development, the flat plate and parabolic trough solar collector were reported for multipurpose applications like solar air heaters and dryers [5, 6]. Besides, the thermal performance of solar collectors may vary due to the solar air temperature, and the flat plate solar collector was utilized for low temperature application and limited thermal efficiency due to the extended area of the flat plate [7]. Researchers are forced to enhance the thermal performance of solar collectorsby implementing different techniques like modification of solar collector orientation [8], utilizing nanofluids [9], adopting coating materials [10], and implementing optimization analysis tools [11], *etc.*

The effect of nanofluids (CuO, Al_2O_3, and TiO_2 particles) on the thermal performance of solar collectors configured with heat pipe flat plates was experimentally evaluated by different flow rates and reported that CuO based nanofluid offered maximum thermal performance related with water fluid and improved collector efficiency as 2.95% [12]. Henein and Rehim [13] studied the thermal characteristics of the heat pipe and tube solar collector adopted with MgO and multi-walled carbon nanotube (MWCNT) as ratios of 80/20, 70/30, 60/40, and 50/50 weight percentages and evaluated by 3l per minute rate of flow. The 50/50 ratios of MgO/MWCNT were noted by maximum thermal characteristics and increased efficiency of 77.14%. With the adaptations, MgO nanofluids instated from water fluid in heat pipe solar collector found the progressive enhancement in thermal efficiency (72.4%) compared to water fluid [14]. Maridurai *et al.* [15] reviewed the concentrated solar collector for direct steam production applications and reported that solar collector-based power generation is the future trend. The thermal efficiency of heat pipe solar collector with eight pipes assembly was enhanced by using Al_2O_3-water and TiO_2-water nanofluid and reported that the TiO_2-water nanofluid facilitated higher thermal efficiency of 64% with improved solar power of 35.6% [16]. Besides, Shafieian *et al.* [17] experimentally proved and reported that the mass-flow rate of nanofluid could decide the thermal performance of heat pipe solar water heater set-up. Likewise, Venkatesh *et al.* [18] reported that the solar absorber properties were enhanced by a higher flow rate (0.0316 kg/sm^2). Dehaj *et al.* [19] experimentally evaluated and studied the performance of CuO nanofluid adopted heat pipe solar collector under different volume concentrations of CuO at a varied flow rate of 8 Lpm and 14 Lpm and found that the 0.008 vol. fraction found to be better thermal efficiency of 80% at a higher flow rate of 14 Lpm. However, the thermal management system will be adopted to monitor solar performance conditions [20].

From the aforementioned literature, we found that nanofluid concentration enhanced solar collector efficiency instead of water fluid. The main research gap on solar collectors is lower thermal performance and heat loss due to extended contact area. The main research objective is to enhance the thermal performance of heat pipe solar absorbers by utilizing CuO nanofluid with concentrations of 0.005, 0.01, and 0.015 volume fractions under different mass-flow rates. The effect of nanofluid on temperature gain, heat transfer coefficient and thermal efficiency of HPSA is experimentally evaluated, and its results are compared with water fluid results.

Materials and methods

Details of materials

In the group of nanofluids, CuO found significant qualities such as superior thermal conductivity, enhanced solar absorption, and good stability [9]. It is considered for this investigation, and different concentrations are utilized for experimental evaluation. Earlier, the CuO was taken as 0.008% and 0.017% concentration for enhancing the thermal efficiency of the heat pipe solar collector [19]. According to this present investigation, the volume concentration of CuO is fixed by 0.010%, 0.015%, and 0.020% volume concentration. The characteristics of CuO nanofluid are addressed in tab. 1.

Table 1. Characteristics of water and CuO nanofluid

Properties of fluids	Unit	Fluid medium	
		Water	CuO nanofluid
Density, ρ	[kgm^{-3}]	997.77	6315
Thermal conductivity, k	[Wm^{-1}K^{-1}]	0.598	18
Specific, C_p	[Jkg^{-1}K^{-1}]	4179	540

Experimental details

Figure 1 depicts the heat pipe solar absorber set-up configured with the solar analyzer. It consists of 30 absorber aluminum pipes of 40 mm diameter and 1700 mm length covered with 50 mm glass, which helps to minimize heat loss during thermal absorption [4]. The fluid-flow was directed through the pump and control valve set-up, and the solar radiations and temperature were analyzed via a solar analyzer. The specification of heat pipe and solar absorber is mentioned in tab. 2. The solar collector performance is initially evaluated by water medium, and then CuO nanofluid is executed with different volume concentrations.

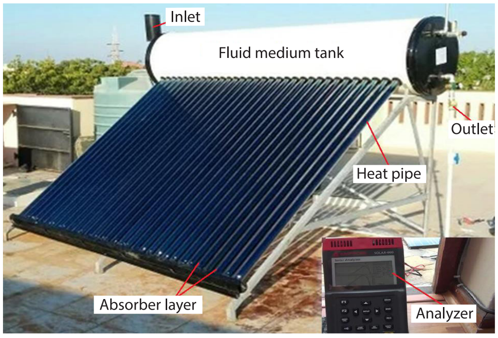

Figure 1. Actual set-up of heat pipe solar absorber with the solar analyzer

Table 2. Specification of heat pipe solar absorber

Descriptions	Units
Diameter of pipe	40 mm
Thickness	3 mm
Diameter of glass cover	50 mm
No of pipes	30 nos
Length of pipe	1700 mm
Material	Al
Nanofluid used	water and CuO
Distance between two tubes	50 mm

The water is filled in the storage tank and circulated at different flow rates of 18 Lpm. Monitored the temperature variations from 8.00 a. m. to 6.00 p. m. for five days, and its average values are considered. With the help of a thermocouple and digital solar analyzer, the temperature of the working fluid and solar radiation is measured. Besides, the anemometer was utilized to measure the air velocity.

The experimental study is executed with:
– water fluid medium,
– 0.01 volume concentration of CuO nanofluid,
– 0.015 volume concentration of CuO nanofluid, and
– 0.020 volume concentration of CuO nanofluid on 18 Lpm flow rate on temperature gain, heat transfer coefficient, and thermal efficiency of heat pipe solar absorber are evaluated and compared.

Uncertainty analysis

The present experimental investigation on the thermal performance of heat pipe solar absorbers is evaluated with a diverse range of measuring parameters and their uncertainty analysis of instruments derived by model, accuracy, and percentages, as shown in tab. 3.

Table 3. Uncertainty analysis

Name of instrument	Model	Range	Accuracy	Percentage of uncertainty
Solar analyzer	S600	(Dew point) 100-20 °C	2	0.02%
		(Temperature) 0-100 °C	±0.1 K	0.05%
Thermocouple	0-220 °C	COM1706	2.1 °C	±1 °C
Anemometer	0-30 m/s	PCE	±1	±1%

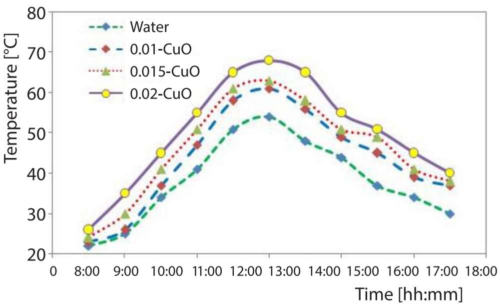

Figure 2. Variations in temperature gain of fluid on heat pipe solar absorber

Results and discussions

Temperature gain

Figure 2 presents the variations in temperature of fluid medium noted with their effect of heat pipe solar absorber operates with water and CuO nanofluid under 18 Lpm flow rate.

Here, the system of fluid temperature is noted every hour from 8.00 a. m to 6.00 p. m for five days. The temperature gain of HPSA operated with water and CuO nanofluid at different volume fractions showed that the temperature steadily improved up to 1.00 p. m. Afterwards, the temperature showed a gradual downtrend. Besides, the temperature gain of CuO-concentrated nanofluid is higher than that of the water fluid medium. Henein and Rehim [13] reported that the temperature of the solar collector system was improved gradually and attained maximum temperature on peak hours of sunlight radiation.

The temperature of water fluid increases from 22-54 °C between 8.00 a. m. to 1.00 p. m. and gradually decreases to 30 at 6.00 p. m. It was due to the variations in solar concentration [7]. Among the various groups, the heat pipe solar absorber operated with 0.020 volume fraction of CuO nanofluid at 18 Lpm flow rate offered a maximum temperature gain of 68 °C at 1.00 p. m. The temperature enhancement was due to the CuO nanofluid [9]. The maximum flow rate of nanofluid was the prime source for the improved temperature of the heat pipe solar collector [19]. However, the CuO action with 0.020 volume fraction at 18 Lpm flow rate found a maximum temperature gain of 68 °C and enhanced by 26% compared with water fluid for similar conditions. Based on understanding purpose, each fluid's temperature gain (1.00 p. m.) is detailed in fig. 3.

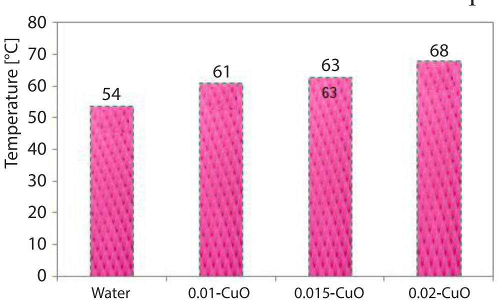

Figure 3. Temperature gain measured by solar peak time (1.00 p. m.) at 18 Lpm

Heat transfer coefficient

The influence of CuO nanofluids with different volume fractions on the heat transfer coefficient of heat pipe solar absorber is evaluated with a higher flow rate, as displayed in fig. 4. The heat transfer coefficient of heat pipe solar absorber operates with CuO nanofluid found to higher than the water fluid medium due to the concentration of CuO nanofluid facilitated good thermal gain rather water fluid and evidenced in fig. 2.

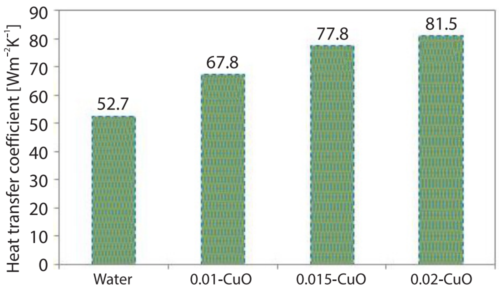

Figure 4. Heat transfer coefficient of heat pipe solar absorber

Here, the heat pipe solar absorber investigated with water fluid showed the nominal amount of heat transfer coefficient (52.7 W/m^{2}K), and the experiment carried with 0.010 volume fraction of CuO nanofluidwas found to be 67.87 W/m^{2}K because the thermal conductivity of CuO nanofluid was higher than the water [5]. Likewise, the concentration of CuO nanofluid increases with a higher flow rate recorded superior heat transfer coefficient and the maximum heat transfer coefficient is noted by 81.57 W/m^{2}K on 0.020 volume concentration of CuO nanofluid operated at 18 Lpm, which is hiked by 55% compared to water fluid. Moreover, the action of heat pipe solar absorber arranged with an even gap facilitates good thermal performance [19].

Thermal efficiency

Figure 5 indicates the thermal efficiency of HPSA executed with water and CuO nanofluid at a higher flow rate. Based on the nature of the condition, utilizing nanofluid and its concentration and flow rate, the thermal efficiency of the solar collector was varied [8, 9]. Moreover, various types of research were extracted, enhancing the thermal efficiency of heat pipe solar collector systems by implementing MgO/MWCNT found 77.14% [13]. Here, CuO nanofluid facilitates good thermal efficiency and relates to temperature gain. The thermal efficiency of water fluid-operated HPSA was lower than the CuO-operated HPSA system.

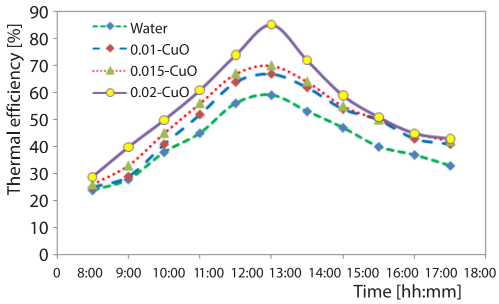

Figure 5. Thermal efficiency of heat pipe solar absorber

It was progressively increased to 1.00 p. m. after it was a downtrend. Specifically, the HPSA with 0.010, 0.015, and 0.020 volume fractions of CuO nanofluidhas good thermal efficiency, observed as 67%, 70%, and 85.2%, respectively. The maximum thermal efficiency of 85.2% was noted by the 0.020 volume fraction of CuO nanofluid executed with an 18 Lpm flow rate. The enhancement of thermal efficiency was due to CuO making better thermal conductivity than water fluid. However, the nanofluid concentration and its higher flow rate were found to have maximum thermal efficiency and 10.44% higher than the past literature [13].

Based on the investigation, tab. 4 illustrates the comparative analysis for the present research (thermal efficiency of HPSA system). Test results values are compared with past literature.

Table 4. Comparative analysis of heat pipe solar absorber with recent literature

NanoFluid	Thermal efficiency	Reference No.
MgO/MWCNT (50/50)	77.14	13
MgO-water (0.014 vol.)	72.4	14
TiO_2-water (2%)	64	16
CuO-water (0.017 vol. fraction)	80	19
CuO-water (0,020 vol. fraction)	85.2	Present research

The present investigational results of thermal efficiency of HPSA operated with 0.020 volume fraction at 18 Lpm flow rate has significant improvement and its results compared with recent literature, this system thermal efficiency enhanced by 10% [13], 17.6% [14], 33% [16], and 6.5% [19].

Conclusions

By utilizing CuO nanofluid at varied volume fractions, the heat pipe solar absorber's thermal properties were enhanced and compared with water fluid. The effect of CuO nanofluid on temperature gain, heat transfer coefficient, and thermal efficiency of the HPSA system was experimentally evaluated. The main key findings and future work are addressed below based on the experimental evaluation, the conclusion are as follows.

- Among the various fluid mediums, the CuO-operated fluid medium found good thermal behaviours, and a 0.020 volume fraction at a higher flow rate offered an enhanced temperature gain of 68 ºC at noon.
- Likewise, the heat transfer coefficient of 0.020 volume fraction of CuO nanofluidwas maximum (81.5 W/m^2K), hiked by 55% related to water fluid medium.
- Similarly, the thermal efficiency on 0.02 volume fraction of CuO nanofluid operated heat pipe solar absorber observed higher solar efficiency of 85.2% at 18 Lpm.
- The developed system with optimum heat pipe solar collector behaviour is suggested for heat exchange applications and future aspects. The flow rate was varied, and the performance of HPSA.

Declarations

Funding statement: No funding was used for this study.

Conflicts of interest: Authors declare no conflicts of interest.

Data availability: All the data required are available within the manuscript.

Acknowledgment

The authors would like to acknowledge the Researchers Supporting Project number (RSP2024R5), King Saud University, Riyadh, Saudi Arabia.

References

[1] Bagherian, M. A., K. Mehranzamir, K., A Comprehensive Review on Renewable Energy Integration for Combined Heat and Power Production, *Energy Conversion and Management*, *224* (2020), 113454

[2] Marimuthu., S., *et al*., Performance Study on Glazzed Solar Air Heater for Agri Products, *Materials Today Proceedings*, *69* (2022), 3, pp. 633-636

[3] Venkatesh, R., Vijayan, V., Performance Evaluation of Multipurpose Solar Heating System, *Mechanical and Mechanical Engineering*, *20* (2016), 4, pp. 359-370

[4] Venkatesh, R., Christraj, W., Experimental Investigation of Multipurpose Solar Heating System, *Journal of Energy Engineering*, *141* (2013), 3
[5] Kumar., Y., *et al*., Recent Developments in the Thermal Performance of Flat Plate Solar Water Heaters with Reflectors-A Review, Energy Sources – Part A: *Recovery, Utilization, and Environmental Effects*, *44* (2022), 4, pp. 9448-9475
[6] Ajbar., W., *et al*., Different Ways to Improve Parabolic trough Solar Collectors' Performance over the Last Four Decades and Their Applications, A Comprehensive Review, *Renewable and Sustainable Energy Reviews*, *156* (2022), 111947
[7] Pandey, K. M., Chaurasiya, R., A review on Analysis and Development of Solar Flat Plate Collector, *Renewable and Sustainable Energy Reviews*, *67* (2017), Jan., pp. 641-650
[8] Kostic., L. T., *et al*., Optimal Design of Orientation of PV/T Collector with Reflectors, *Applied Energy*, *87* (2010), 10, pp. 3023-3029
[9] Jayaseelan, G. A. C., *et al*., Assessment of Solar Thermal Monitoring of Heat Pump by Using Zeolite, Silica Gel, and Alumina Nanofluid, *Clean Technologies and Environmental Policy*, *25* (2023), June, pp. 3075-3083
[10] Maio, D. D., *et al*., Solar Selective Coatings for Evacuated Flat Plate Collectors: Optimization and Efficiency Robustness Analysis, Solar Energy Materials and Solar Cells, *242* (2022), 111749
[11] Moustafa., E. B., *et al*., A New Optimized Artificial Neural Network Model to Predict Thermal Efficiency and Water Yield of Tubular Solar Still, *Case Studies in Thermal Engineering*, *30* (2022), 101750
[12] Allouhi, A., Amine, M. B., Heat Pipe Flat Plate Solar Collectors Operating with Nanofluids, *Solar Energy Materials and Solar Cells*, *219* (2021), 110798
[13] Henein, S. M., Rehim, A. A. A., The Performance Response of a Heat Pipe Evacuated Tube Solar Collector using MgO/MWCNT Hybrid Nanofluid as A Working Fluid, *Case Studies in Thermal Engineering*, *33* (2022), 101957
[14] Dehaj, M. S., Mohiabadi, M. Z., Experimental Investigation of Heat Pipe Solar Collector Using MgO-Nanofluids, Solar Energy Materials and Solar Cells, *191* (2019), Mar., pp. 91-99
[15] Maridurai., T., *et al*., Review on Direct Steam Generation Using Concentrated Solar Collectors, *AIP Conference Proceedings*, *2473* (2022), 1, 020008
[16] Unvar., S., *et al*., Improvement of Heat Pipe Solar Collector Thermal Efficiency Using Al_2O_3-Water and TiO_2-Water nanofluids, *International Journal of Photoenergy*, *2021* (2021), ID5546508
[17] Shafieian, A., *et al*., Enhancing Heat Pipe Solar Water Heating Systems Performance Using a Novel Variable Mass-Flow Rate Technique and Different Solar Working Fluids, *Solar Energy*, *186* (2019), July, pp. 191-203
[18] Venkatesh, R., Chirstraj, W., Performance Analysis of Solar Water Heater in Multipurpose Solar Heating System, *Applied Mechanics and Materials*, *592* (2014), July, pp. 1706-1713
[19] Dehaj, M. S., Mohiabadi, M. Z., Experimental Study of Water-Based CuO nanofluid-Flow in Heat Pipe Solar Collector, *Journal of Thermal Analysis and Calorimetry*, *137* (2019), Mar., pp. 2061-2072
[20] Baskar., S., *et al*., Thermal Management of Solar Thermoelectric Power Generation, *AIP Conference Proceedings*, *2473* (2022), 1, 020010

Paper submitted: March 11, 2023
Paper revised: August 26, 2023
Paper accepted: October 5, 2023