STUDY ON A SOLAR WATER HEATER
PERFORMANCE UNDER THE INFLUENCE OF NANOFLUID

STUDIU PRIVIND PERFEZIONĂTÂ A UNUI ÎNCĂLZITOR DE APĂ SOLARĂ SUB INFLUENȚA NANOFLUIDELOR

P. MANOJ KUMAR¹, M. RAJESWARI², P. T. SARAVANAKUMAR³, SP. ARUNKUMAR⁴, P. Michael Joseph STALIN⁵

Abstract: Globally, a significant amount of energy is spent to produce hot water for processing industries, domestic requirements, commercial buildings, and so on. In such cases, the deployment of solar water heating systems has been identified as a competent solution, considering their environment-friendly operation and affordability. In the current work, an investigation was piloted to examine the influence of deploying nano-CeO₂/water nanofluid as circulating fluid in an evacuated tube solar water heater (ETSWH) at mass fluxes of 1.002 kg/min and 10.02 kg/min, respectively. The outcomes revealed that the incorporation of nano-CeO₂/water nanofluid boosted the ETSWH system’s peak temperature gradient and daily average efficacy to 40 °C and 75%, respectively.

Keywords: evacuated tube, nanofluid, nano-CeO₂/water, solar water heater, thermal efficiency.

Rezumat: La nivel global, o cantitate semnificativă de energie este cheltuită pentru a produce apă caldă pentru industriile de prelucrare, cerințele interne, clădirile comerciale și așa mai departe. În astfel de cazuri, implementarea sistemelor solare de încălzire a apei a fost identificată ca o soluție competentă, eficientă din punct de vedere termic.

¹ Associate Professor, Department of Mechanical Engineering, KPR Institute of Engineering and Technology, Coimbatore - 641407, Tamil Nadu, India, e-mail: pasupathimanojkumar@gmail.com
² Associate Professor, Department of CSE, Karunya Institute of Technology and Sciences, Coimbatore, Tamil Nadu, India, e-mail: rajeswari@karunya.edu
³ Professor and HoD, Department of Mechatronics Engineering, Hindusthan College of Engineering and Technology, Coimbatore – 641032, Tamil Nadu, India, e-mail: ptscfd@gmail.com
⁴ Associate Professor, Department of Mechatronics Engineering, Nehru Institute of Engineering and Technology, Coimbatore, Tamil Nadu, India, e-mail: arungreesma@gmail.com
⁵ Department of Mechanical Engineering, Audisankara College of Engineering & Technology, Gudur - 524101, Andhra Pradesh, India, e-mail: pmjstalin@gmail.com
Cuvinte cheie: tub evacuat, nanofluid, nano-CeO$_2$/apă, încălzitor de apă solară, eficiență termică.

1. Introduction

The present global energy scenario demonstrates that almost all nations internationally rely heavily on petroleum-based energy sources to satisfy their energy requirements. Such petroleum-based fuels contribute to more than 75 percent of the world's total energy generation. With the present rate of consumption, the scenario with petroleum resources is extremely concerning, as are their ecological issues [1, 2]. Conserving energy reserves has become a global concern in recent times. In order to overcome the issues with traditional petroleum-based fuels and conserve the environment, the researchers have been investigating new-age unconventional energy sources, including wind farms, micro-hydro, biogas, geothermal, hydrogen-based, and solar-based sources [3, 4]. Among them, solar-based energy sources have several advantages over conventional ones. Solar-based systems are capable of directly harnessing both electrical and thermal energy with the aid of photovoltaic panels and solar collectors, respectively [5, 6]. Solar energy has various benefits, including the fact that it is a clean and green source that is eco-friendly in nature. Further, it is abundantly available without any cost and readily usable with the available technologies [7].

It is reported that a significant quantity of energy has been used worldwide in commercial buildings, residential apartments, and many processes across several sectors only to produce hot water [8]. The radiative heat energy from the sun can be deployed efficiently through solar water heating systems to heat the water for various applications. The thermal energy requirement, the desirable thermal gradient, and the cost of the system must all be taken into consideration when choosing a solar collector for a solar water heating system. Because of their straightforward operating principle, ease of maintenance, and inexpensive configuration, evacuated tube solar water heaters (ETSWHs) are the most frequently used solar water heaters.
worldwide [4]. When designing a cost-effective ETSWH, one of the main considerations is its efficacy [7].

The efficacy of the ETSWHs can be enhanced by modifying the optical characteristics of the absorber coatings, incorporating phase-changing materials, incorporating twisted tapes and finned tubes, improving the properties of the working fluids, and so on [9]. The efficacy of the solar collecting arrangement was increased by Anirudh and Dhinakaran [10] with the use of interconnected permeable slabs. Within close proximity to the collector's lower insulated plate, the slabs had been fixed. Utilizing a phase-changing medium with fin integration, Badiei et al. [11] increased the solar collector's thermal performance. As shown by their findings, the use of such fins increases the thermal storage capability of the phase transition materials. In another work, Kansara et al. [12] enhanced the collector's efficacy of the solar thermal system through the amalgamation of porous medium with the internally arranged fins. Comparing the modified collector to the traditional collector, their findings indicated an increase in efficacy.

Among the most crucial components that need to absorb heat energy from the solar collector is the heat-transferring medium (circulating fluid), and one of the greatest ways to improve the heat exchange rate in the collectors under consideration is to use nanofluid rather than an ordinary heat-transferring fluid [13]. A suspension of fluid that possesses a meagre quantity of nano-sized grains (less than 100 nm), has been referred to as a nanofluid [14]. The chosen nanoparticles would have high thermal conductivity. The addition of such nanoparticles in tiny quantities to a conventional working fluid substantially increases the heat conductivity of that fluid [15]. The research scholars have characterized and studied a number of nanofluids, especially for systems involving unconventional energy [2, 7, 9]. It is proven that thermal efficiency rises when nanofluids are used in solar thermal systems [13, 15].

Sabiha et al. [16] examined the ETSWH's efficacy using a nanofluid containing carbon nanotubes. They deployed water as a base fluid in their work. The testing results demonstrated a significant enhancement in the ETSWH's thermal performance. Additionally, it was observed that the highest output temperature occurred when the volume of nanofluid was contained at 0.2 percent. A study was conducted by Mahbubul et al. [17] to determine the impact of utilizing single-walled carbon nanotubes with the base fluid on the thermal performance of the ETSWH system. The findings revealed that the ETSWH systems incorporated with the nanofluid enhanced the efficacy of the system by 9.3%. The efficacy of ETSWH, consisting of an interior coil, was investigated by Ghaderian et al. [18]. They deployed a small volume of copper oxide
nanoparticles within the base fluid. They noticed a significant enhancement in the performance of the ETSWH system using the aforementioned nanofluid.

The present work is aimed at examining the influence of a nanofluid consisting of cerium oxide nanoparticles within the water (nano-CeO$_2$/water) on the performance of the ETSWH system under two mass fluxes of 1.002 kg/min and 10.02 kg/min. The detailed experimental procedure and the outcomes of the work are discussed in the following sections.

2. Experimental test rig

The passive flow type ETSWH with ten numbers of evacuated tubes was assembled and installed at the study site, as shown in Figure 1. The tubes were 180 cm in length and 47 mm in inner diameter, as per the local standard. Each evacuated tube was coated with an aluminium nitride and copper-based selective coating, which enhanced the solar reception of the tubes to a significant level for effectively harnessing the solar radiative heat during the operation. The tubes were meticulously joined to the fluid tank with leak proof gaskets. The tank was perfectly insulated with the aid of commercially available thermal insulating material to curb heat losses. The instrumentations were meticulously made to observe the hourly readings of the nanofluid temperatures and the incidental solar insolation. In this case, thermocouples (0.5 °C accurate) were deployed for recording ambient and nanofluid temperatures. A solar power meter with ±10 W/m$^2$ was employed for the observation of instantaneous solar radiation. During the examination, the test rig was placed in such a way that its collectors were facing south, as per the recommendations from the earlier literature [4, 7].

![Figure 1. Experimental test rig](image)
3. Synthesizing nano-CeO₂/water nanofluid

The nano-CeO₂/water nanofluid was synthesized by a two-step technique as proposed by the literature [2, 4]. The nano-CeO₂ particles with 99.9% purity and an 80 nm mean particle size and the high-quality calcium carbonate nanoparticles of 80 nm size were obtained from a renowned international vendor. The nano-CeO₂ particles were considered in this study owing to their superior thermal conductivity [7], and calcium carbonate nanoparticles were used as a surfactant [19] to obtain a homogeneous form of nanofluid without any precipitation. The water was distilled before synthesizing the nanofluid to ensure that it was free from impurities. A 0.005% concentration of calcium carbonate nanoparticles was initially dispersed in water at an elevated temperature using a magnetic stirrer, and agitation was sustained for 90 min. Then, the nano-CeO₂ particles of a 0.05 volume fraction were slowly and steadily added to the stabilized base fluid using the magnetic stirrer, and once again, the nanofluid was maintained in stirring for another 90 minutes to obtain the required nanofluid with a high degree of stability, as illustrated in Figure 2.

![Figure 2. Preparation of nanofluid](image)

4. Method of investigations

The entire investigation was carried out in June 2022 at 11.0765° N, 77.1420° E, which is located in the southern part of India. The experiments were carried out using the ETSWH test rig in four different scenarios. The first scenario was with ‘water at 1.002 kg/min’, and the second scenario was with ‘water at 10.02 kg/min’. The third and fourth scenarios were with ‘nano-CeO₂/water nanofluid at 1.002 kg/min’ and ‘nano-CeO₂/water nanofluid at 10.02 kg/min’, respectively. The test trials were piloted for eight hours on each scenario during each experimental day. The observations on the temperatures and solar irradiation were taken on an hourly basis, and the
following Equations (1) and (2) were used to determine the performance of the ETSWH system under the four scenarios mentioned [2].

\[ Q_w = mC_p(T_{out} - T_{in}) \]  

(1)

\[ \eta = \frac{Q_w}{A_{ct}S_{in}} \times 100 \]  

(2)

Where ‘\( Q_w \)’ denotes the energy gained by the water/nanofluid, which was calculated by the mass flux (\( m \)), specific heat of the circulating fluid (\( C_p \)), inlet temperature (\( T_{in} \)), and outlet temperature (\( T_{out} \)) of the fluid, as given in Equation (1). Further, ‘\( \eta \)’ denotes the efficacy of the system, which was determined by solar energy gain (\( Q_w \)), area of the solar collector (\( A_{ct} \)), and incident solar energy (\( S_{in} \)), as mentioned in Equation (2).

5. Results and discussion

As mentioned in the earlier section, the testing trials were accompanied for eight hours between 9.00 and 16.00 IST (Indian Standard Time) during all the scenarios on each experimental day. The experimentations on each scenario were organized for at least a week to ensure the accuracy of the outcomes, and the days with identical environmental conditions were taken for further calculations and analysis.

![Figure 3. Hourly changes in solar insolation](image-url)
Figure 3 represents the recorded solar radiation intensity during the trials. The mean radiation intensity was determined to be 760 Watts per square meter, and the variation of the received solar irradiation seems to be undistinguishable in all the experimental scenarios. Likewise, the disparities in atmospheric temperature were not much deviated during the time of all experimental scenarios, as illustrated in Figure 4. Further, the daily average atmospheric temperature was observed as 31.5 °C, which was almost common during all four experimental scenarios. From Figure 3 and Figure 4, it could be clearly understood that the investigational trials were piloted with the ETSWH test rig in undistinguishable ambient conditions, which helped to interpret the results unambiguously.

![Figure 4. Hourly changes in ambient temperature](image)

Figure 5 demonstrates the temperature gradient between inlet and outlet water/nanofluid temperatures during the investigations. It is vividly noticed that the temperature gradient increased positively from the forenoon to the afternoon and slightly declined after noon towards the end of the day. It shows that the temperature of the working fluids depends on the solar radiation and the ambient temperature. Further, the temperature gradient was lessened with the increase in mass flux. Comparing to the scenario ‘water at 10.02 kg/min’, the temperature gradients of the scenario ‘water at 1.002 kg/min’ were higher at each time interval, owing to the increased residential of the fluid at the lower mass flux. Likewise, compared to the scenarios with
‘water’, the scenarios with ‘nano-CeO\textsubscript{2}/water nanofluid’ outperformed at both mass fluxes. However, the ETSWH system with the nano-CeO\textsubscript{2}/water nanofluid has exhibited superior performance at a mass flux of 1.002 kg/min compared to a mass flux of 10.02 kg/min. The maximum temperature gradients of 26 °C and 40 °C were recorded at 1.002 kg/min with water and nano-CeO\textsubscript{2}/water nanofluid, respectively. Similarly, the maximum temperature gradients of 20 °C and 31 °C were recorded at 10.02 kg/min with water and nano-CeO\textsubscript{2}/water nanofluid, respectively. The ETSWH system with nano-CeO\textsubscript{2}/water nanofluid and at 1.002 kg/min exhibited a 14 °C increment in the temperature gradient compared to the corresponding system with water as the working medium. Hence, the results vividly indicate that the utilization of nano-CeO\textsubscript{2}/water nanofluid has suggestively improved the temperature gradient of the system at a mass flux of 1.002 kg/min.

![Temperature gradient during the test trials](image)

**Figure 5.** Temperature gradient during the test trials

Figure 6 illustrates the thermal efficacy of the ETSWH systems in four different experimental scenarios. The peak instantaneous efficacy of the ETSWH system was recorded after noon in all four scenarios. They are 70%, 65%, 90%, and 82% for the scenarios ‘water at 1.002 kg/min’, ‘water at 10.02 kg/min’, ‘nano-CeO\textsubscript{2}/water nanofluid at 1.002 kg/min’, and ‘nano-CeO\textsubscript{2}/water nanofluid at 10.02 kg/min’, respectively. Further, the daily average efficacy was 59.25%, 54.88%, 75%, and 69% for the aforementioned scenarios, respectively. The obtained values are comparatively higher than the
study conducted by Janardhana et al. [20], where they used a hybrid nanoparticle (copper oxide and magnesium oxide nanoparticles) with water as a circulating fluid. Once again, it is evident that the ETSWH system with nano-CeO2/water nanofluid. It can be attributed to the incorporation of nanofluid. Furthermore, the nano-CeO2/water nanofluid extended its flowing period at a reduced mass flux of 1.002 kg/min, which in turn prolonged the rate of energy absorption due to the longer residence time of the working fluid within the system at this low mass flux. In this way, the best efficiency of the system was recorded at 1.002 kg/min with nano-CeO2/water nanofluid, compared to all the scenarios.

![Thermal efficacy during the test trials](image.png)

**Figure 6.** Thermal efficacy during the test trials

### 6. Conclusions

The experimental investigation was carried out on the ETSWH system to assess its thermal performance under the influence of nanofluid (nano-CeO2/water nanofluid) at two mass fluxes (1.002 kg/min and 10.02 kg/min). The ETWSH system produced a 40 °C temperature gradient with nano-CeO2/water nanofluid at 1.002 kg/min, which was 14 °C higher than the system with water at a similar mass flux. Further, the highest peak instantaneous efficacy and daily average efficacy were observed with nano-CeO2/water nanofluid at 1.002 kg/min, which were 90% and 75%, respectively. Hence, the results evinced that the ETSWH system was very effective with nano-CeO2/water nanofluid at 1.002 kg/min mass flux.
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Authors' biographies

P. Manoj Kumar has been recognized as ‘World Top 2% Scientists 2022 and 2023’ by Stanford University and Elsevier. He has 14 years of teaching experience and 6 years of research experience. His research interests include solar thermal conversion, thermal energy storage, and phase change materials. He has published more than 60 research papers in reputed, peer-reviewed international journals; published five book chapters; authored five books; and presented more than 100 papers at international and national conferences.

Email: pasupathimanojkumar@gmail.com
M. Rajeswari is currently working as an Associate Professor in the Department of Computer Science and Engineering in Karunya Institute of Technology and Sciences, Coimbatore. She has received Ph.D. degree in Information and Communication Engineering from Anna University, Chennai in the year 2016. She is having more than 16 years of experience in teaching. She has published more than 50 papers in various International Journals and presented more than 20 papers in both national and International Conferences. She is also an active member in ISTE, CSI, IAENG, SDIWC and IS.

Email: rajeswari@karunya.edu

P.T. Saravanakumar is presently working as Professor in the Department of Mechatronics Engineering, Hindusthan College of Engineering and Technology, Coimbatore, India. He did his research on Thermal Performance Analysis of Flat Plate Forced Convection Solar Air Heater with and without thermal Storage materials and obtained Doctorate degree in the year 2015 from Anna University, Chennai. His research interest includes Solar Energy, Nano Materials, and Computational Fluid Dynamics & Heat Transfer.

Email: ptscfd@gmail.com

SP. Arunkumar is presently working as Associate Professor in the Department of Mechatronics Engineering, Nehru Institute of Engineering and Technology, Coimbatore, India. He is completed Ph.D. in Anna University, Chennai in the field of Alternate refrigerants. He has teaching experience of 17 years and industrial experience of 2 years. He has published 24 International Journals, one National Journal and 22 National and International Conferences. His research interest includes Alternate refrigerants, Alternate fuels, Solar energy.

Email: arungreesma@gmail.com

P. Michael Joseph Stalin is presently working as Associate Professor in the Department of Mechanical Engineering, Audisankara College of Engineering & Technology, Gudur, India. He did his research on Experimental Investigation on the Effects of CeO₂/Water Nanofluid in Flat Plate Solar Water Heater and obtained Doctorate degree in the year 2019 from Anna University, Chennai. His research interests include Solar Thermal Systems, Nanofluids in Heat Transfer Applications, Hybrid Nanofluids and Composite Materials.

Email: pmjstalin@gmail.com