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Performance Evaluation of CeO_2/Water Nanofluid in Flat Plate Solar Water Heating System: Experimental Analysis and Comparative Study

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Abstract

The performance of solar water heating systems depends significantly on the collector design, working fluid, and stratification management within the storage tank. This study investigates the thermal performance of a forced-circulation flat plate solar water heating system utilizing CeO_2/water nanofluid as the working medium. The experimental setup was designed and installed in Bhopal, India, and performance was evaluated at varying nanofluid concentrations (0.01%, 0.05%, and 0.1%) and flow rates (1–3 L/min). Comparative analysis with conventional Al_2O_3/water nanofluid was also performed to assess the heat transfer augmentation potential of cerium oxide nanoparticles. Results revealed that CeO_2/water nanofluid achieved a maximum efficiency of 81.2% at 0.05% concentration and 2 L/min flow rate. Efficiency increased with flow rate up to 2 L/min due to improved convective heat transfer and decreased at higher flow rates due to reduced residence time. The outlet fluid temperature reached a peak of 78.5 °C, indicating strong thermal stratification and effective heat exchange within the collector. The study further supports that CeO_2 nanofluids provide higher thermal conductivity and stability than Al_2O_3, making them promising candidates for next-generation solar thermal applications.

Keywords:Solar water heater, CeO_2 nanofluid, Flat plate collector, Thermal performance

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1. Introduction

At present, the dominant source of energy for power generation is Coal (40%) followed by gas (23%) and hydroelectric power (17%). The countries have chosen different types of fuels as their major source depending on the availability of resources and the advancement in technology. For example, the nuclear energy contributes the highest percentage in France while hydroelectric power is the dominant source of power generation in Brazil. Renewable energy is one of the rapidly growing sources of energy at the rate of 7.1%. It is expected that renewable energy along with nuclear and hydroelectric power will provide half of the additional energy required by2035 due to its competitiveness (International Energy Agency).

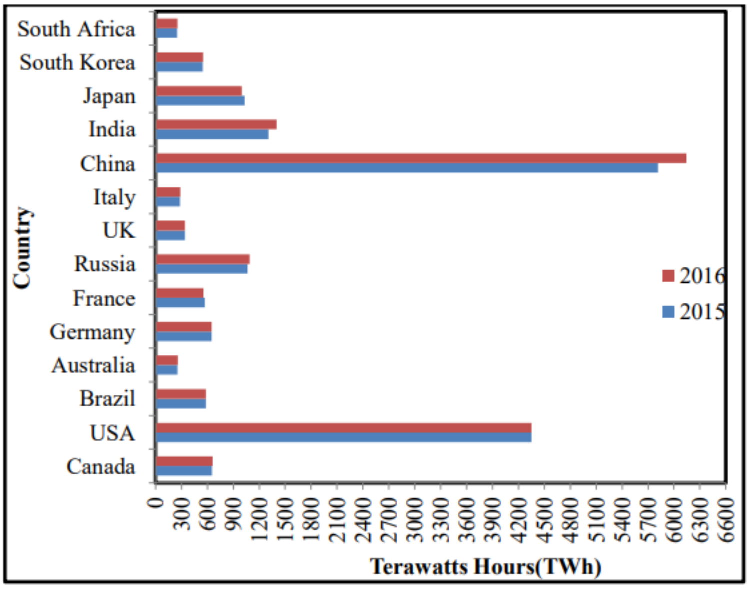

Figure1.Primaryenergygenerationsindifferentcountriesin2015 &2016 (Source: International Energy Agency)

It is seen that coal produces the largest amount of CO2 emission because of electricity generation which is causing global warming nowadays. Necessary measures are being taken up due to which there will be decline in the consumption of conventional fuels (International Energy Agency). In coming years, renewable energies are going to lead and will replace conventional energies which cause pollution. The following Figure 2 and Figure 3 represent the amount of energy consumed by different sectors and the amount of energy generated from various energy resources respectively.

1.1. Solar energy

Solar energy is the energy received in the form of heat and light from the Sun. It is abundantly available and has been utilized as a source of heat for the long time. The source of heat from the Sun varies from time, location, season and atmospheric conditions. The heat is then utilized to produce either hot water

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or hot air in thermal systems depends upon commercial or residential heating purpose in addition to power generation. At present, solar energy is considered as one of the renewable energy sources in the world and considerable research is going on. It is also considered as agreen energy as it does not emit any greenhouse gases. It is calculated that the heat energy received from the Sun for twenty days can be equivalent of all the energy stored in the earth's reserve in the form of coal, oil and natural gas (www.ucsusa.org). The solar radiance is nothing but an instantaneous power density measured in units of kW/m^2. The solar radiance varies throughout the dayand reaches toa maximum of about 1 kW/m^2. It is measured with the help of a pyrheliometer taking radiation at normal incidence. Solar insolation is generally regarded as the solar irradiance which is equal to the total amount of solar energy received during a specified time period at a particular location. The measurement of solar radiation is required for the thermal engineering applications. Solar energy can be used either directly or indirectly as mentioned in Table 1.

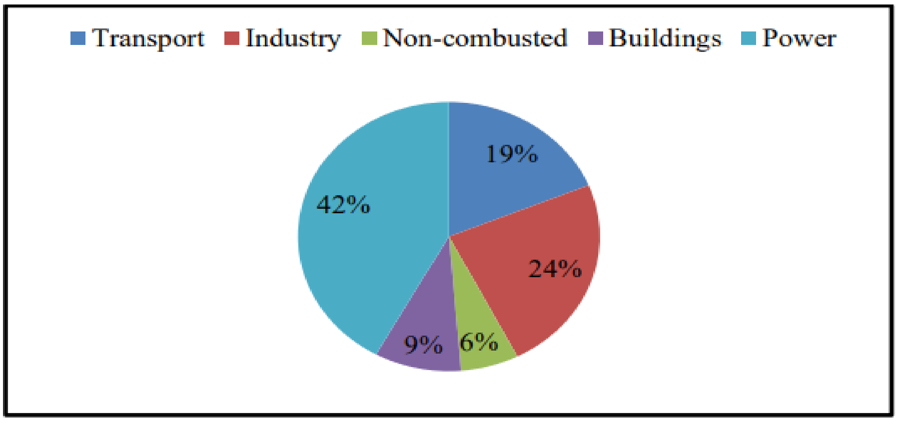

Figure2Primaryenergyconsumptionsofdifferentsectorsinvarious countries (Source: International Energy Agency)

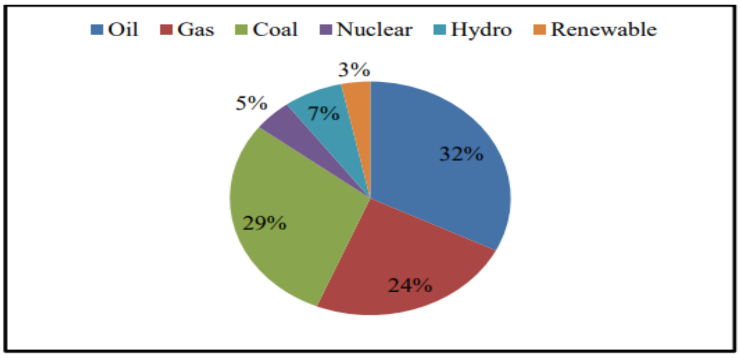

Figure 3Percentageofenergygeneratedfromvariousenergy resources (Source: International Energy Agency)

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Table1.Classificationofsolarenergy utilization

S. No.	Method	Application
1	Direct method	Thermal
		Photovoltaic
2	Indirect method	Wind
		Biomass
		Wave energy
		Ocean thermal energy conversion

1.2. Demand and applications of solar water heating systems

In solar water heating system, heat energy is supplied to get hot water above its room through a thermodynamic process. In India the three sectors which utilize hot water for different applications are domestic, commercial and industrial. In domestic sector, hot water is generally used for cooking, cleaning, bathing and space heating. In the commercial sector, solar water heating systems are mainly used in restaurants, canteens, guest houses, hotels, hospitals, hostels and dormitories. Similarly, in industrial sector, heating of boiler feed water is the major application. Hot water is used in process industries, rice-mill, tea garden, leather, textile processing, dyeing and in food industries.The approximate need ofhot water per dayin allthe sectors is estimated around 3.5 million litres and itkeep on increasing. In 2017, China is the leading country in using solar water heaters and occupies 65.6% of existingglobalsolarwaterheatercapacity(BPenergyoutlook,2017).Itisfollowed by European Union 12.3%, Japan 4.1%, and Israel 2.8%respectively. The Indian share is only about 1.2%.In the residential sector of India,thereare0.7 million solar waterheatersinhouseholds outofwhich65% are concentrated in Karnataka and Maharashtra states only. According to the projected demand, it is expected that 15.74 million solar water heaters would be required in households by the year 2022. The installed area of solar collectors in India as on September 2017 was around 7.96 million sq.m (www.mnre.gov.in). The 3,287,240 sq. km area of India receives solar radiation worth of 5,000 trillion kWh every year, which is equivalent to 430 trillion kg of oil equivalent. Depends upon the location, the day to day average solar energy incident across India is varied from4 to7 kWh/m^2 by considering 2,300 to 3,200 sunshine hours per year.

Table 2SWHpotentialunderrealisticscenario (cumulativemillionm^2)

Year/Utility Type	2010	2013	2017	2025
Residential	2.58	4.25	7.68	15.74
Hotels	0.19	0.35	0.61	0.97
Hospitals	0.10	0.17	0.27	0.43
Others	0.18	0.27	0.39	0.52
Industry	0.19	0.33	0.57	1.05
Total	3.24	5.37	9.52	18.70

2. Literature review

2.1. Studies on solar water heaters

Researchers have extensively examined charging and discharging strategies, thermal storage behavior, and collector designs to enhance the performance of solar thermal systems. Glembin and Rockendorf (2012) demonstrated that maintaining strong thermal stratification in storage tanks significantly improves energy savings, and such stratification can be achieved through properly controlled stratified charging and discharging processes. Chong et al. (2012) introduced a stationary V-trough solar water heating system employing simulated solar concentration, achieving an optical efficiency of up to 70.54%. Their findings highlight the system's potential for developing low-cost and efficient solar water heaters suitable for domestic and commercial applications.

Bellamy (2023) evaluated the thermal performance of a solar-heated stratified concrete wall panel consisting of an internal high-thermal-mass concrete layer and an external insulating layer integrated with a solar collector. The study revealed that this configuration can improve energy performance by more than 15%, suggesting a promising architectural strategy for incorporating low-cost integrated solar collectors in building envelopes to supply moderate-temperature hot water.

Sarver et al. (2024) emphasized the influence of environmental and climatic conditions—such as solar irradiance intensity and spectral distribution—on collector efficiency. Their results also indicated that increasing insulation thickness reduces the absorption coefficient, affecting thermal performance. In another effort to improve system cost-effectiveness, Nwosu et al. (2013) developed a fiber-reinforced plastic thermal storage tank, showing that ambient conditions, tank geometry, and insulation properties strongly affect storage efficiency and heat-retention capability.

Hobbi and Siddique (2025) used TRNSYS to optimize a forced-circulation solar hot water system for cold-climate residential use in Canada. By evaluating parameters including collector area, working fluid type, mass flow rate, and tank capacity, they found that the optimized system could supply up to 97% of summer and 62% of winter hot-water demand. Dickinson et al. (2024) further analyzed the thermal behavior of stratified storage tanks under constant-temperature charging using TRNSYS, offering valuable insights for improving stratified tank performance.

Finally, Chen et al. (2021) investigated heat transfer characteristics in a two-phase thermosyphon operating with CO_2 near its supercritical region. Their study showed that as initial system pressure increases, circulation transitions from unstable sub-critical two-phase flow to stable liquid and eventually to stable supercritical flow. However, sub-critical flow regimeswhether single-phase or two-phase—were observed to induce operational instability.

Overall, these investigations collectively advance the understanding of solar thermal system design, stratified energy storage, and thermofluid behavior, supporting the development of more efficient and reliable solar heating technologies.

3. Methodology

Selection of Standard Nanofluid for Performance Comparisons withCeO2/water Nanofluid

From the literature review, it was observed that most of the researchers (Masuda *et al.* (1993), Eastman *et al.* (2017), Hwang *et al.* (2021), Das *et al.* (2003), Lee *et al.* (2008), Zhu *et al.* (2008), Pastoriza-Gallego *et al.* (2009), Teng and Hung (2014), Wen and Ding (2005), Omid *et al.* (2014), YousefiTooraj*etal.*(2012),Gangadevi*etal.*(2013),HemantKumar Gupta *et al.* (2015) and Gianpiero Colangelo *et al.* (2015) have contributed their study in the development of flat plate solar collector using Al_2O_3/water nanofluid as a heat transfer fluid because it is easilyavailable,economically feasible in addition to possessing better thermo physical properties when compared with other nanofluids. Since various researches are being conducted at presentusing Al_2O_3/water nanofluid in solar thermal systems, present experimental study is aimed to compare the performance of CeO_2/water nanofluid with Al_2O_3/water nanofluid as it is easily available, cheaper in addition to better thermophysical properties. The values of the thermo-physicalpropertiesofthe CeO_2 and Al_2O_3nanoparticles are presented in Table 3.

Table3 Properties of the basefluid,CeO_2andAl_2O_3nanoparticles

Properties	Water	Nanoparticles	
		CeO2	Al2O3
Thermal conductivity (W/mK)	0.52	12	40
Specific heat (J/kg K)	4187	460	765
Viscosity (mPa s)	0.59	-	-
Density (kg/m3)	1000	7132	3970

The values of the thermo-physical properties of the CeO_2/water and Al_2O_3/water nanofluids at various volume concentrations are presented in Table 4.

Table4.Propertiesofthe CeO_2/water and Al_2O_3/water nanofluids

Properties	Nanofluids					
	CeO_2/water			Al_2O_3/water		
	0.01	0.05	0.1	0.01	0.05	0.1
Thermal conductivity (W/mK)	0.681	0.697	0.714	0.626	0.639	0.658
Specific heat (J/kgK)	4164	4152	4139	4169	4158	4143
Viscosity (mPa-s)	0.66	0.68	0.71	0.65	0.67	0.69
Density (kg/m^3)	1004	1010	1018	1001	1007	1013

The experimental setup required for this research work was fabricated and installed at Bhopal, India.

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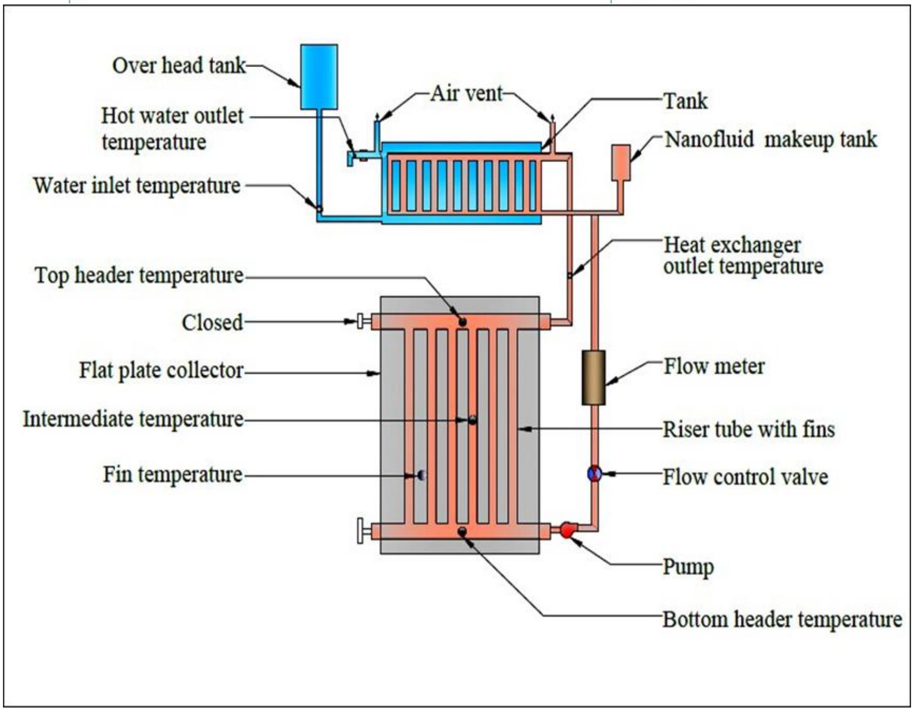

Figure4Schematicdiagramoftheexperimental setup

The important components of forced circulation mode flat plate solar water heater are flat plate collector, absorber plate, storage tank with heat exchanger, nanofluid makeup tank,electricalpump,rotometer,thermocouples, flow control valve, glazing, insulation and support structure. For avoiding the shadow effects, the setup was placed on the roof top of the building so that it gets the maximum exposuretosunlight.The pictorial views of the components employed in the experimental setup are shown in Figure 5.

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Figure5 Majorcomponentsoftheexperimentalsetup

The typical experimental data which was observed in a particular day is given in the Table 5.

Table5 Typicaloneday experimentaldata

TIME	Solar Intensity (W/m2)	T1	T2	T3	T4	T5	T6	T7	T8
		^{0}C	^{0}C	^{0}C	^{0}C	^{0}C	^{0}C	^{0}C	^{0}C
9.00	512.4	30.2	40.2	49.5	46.2	56.4	55.4	48.2	50.2
9.30	568.2	30.4	44.7	50.1	48.4	59.2	56.7	49.1	51.4
10.00	622.5	30.8	47.5	52.4	50.7	62.5	58.3	51	53.7
10.30	705.1	31.6	52.1	55.2	52.4	66.5	60.9	54	57.1
11.00	768.3	32.7	55.7	59.6	54.1	70.1	62.7	56	61.5
11.30	790.2	33.4	58.2	64.1	56.9	74	65.5	59	67.7
12.00	830.5	34	62.0	68.4	59.1	77.2	68.1	62.5	71.8
12.30	872.1	34.6	65.4	70.2	63.4	80.5	70.9	65	75.6
13.00	920.6	35.9	69.8	72.6	65.8	82	72.5	66.3	78.5
13.30	910.4	35.6	68.1	72.9	63.1	81.2	74.1	65	77.1
14.00	865.5	35.2	66.4	70.7	61.5	80.4	71.7	63	73.8
14.30	780.4	34.2	62.5	66.1	60.6	78.1	67.4	61	69.4
15.00	715.4	34.9	58.9	62.4	57.1	75.5	65.2	58	63.7
15.30	675.2	34.4	55.3	57.2	55.4	73	63.5	56	59.8
16.00	585.4	34.2	52.6	54.7	53.1	69.5	61.2	54.5	56.9
16.30	510.2	34	50.2	52.9	50.4	66.5	58.5	52.2	54.0
17.00	446.1	33.6	48.2	50.5	49.9	63.5	55.8	50.5	51.8

Where,T1=Atmospherictemperature,T2=Wateroutlettemperature, T3=Topheadertemperature, T4=Bottomheadertemperature,T5 =Fin temperature,T6= Riser tube temperature,T7 = Collector inlet temperature, T8=Collectoroutlettemperature,

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4. Results and Discussion

4.1. InletandOutlet Temperatureof Solar Collector

Figure 6 represents the ambient, inlet, outlet temperature of solar collector and intensity of solar radiation recorded with respect to time period.Thetemperaturedifferencebetween theoutletand inletfluid increases with the increase in the intensityof solar radiation. The maximumtemperature difference between the outlet and inlet fluid was 12.2°C observed at 13.00 hrs, at an ambient temperature of 35.9°C. The maximum temperatures reached by the outlet and inlet of the solar collector were 78.5°C and 66.3°C respectively which were attained at the time of 13.00 hrs. The inlet working fluid reached the maximum temperature gradually because of the thermal stratification ofthe storage tank temperature and effectiveness of the heat exchanger. It is also observed that the inlet working fluid and outlet working fluid attained almost equal temperature in the absence of solar radiation.

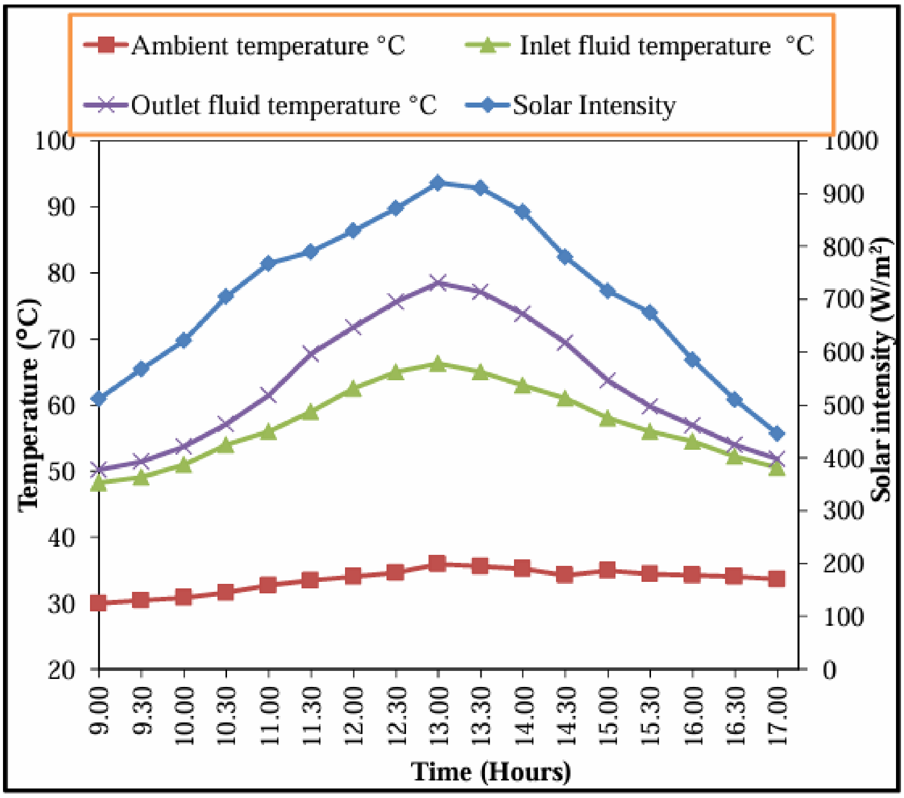

Figure6ExperimentaldataforCeO_2/waterasworkingfluid

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4.2. Effect of Volume Concentrations and Volume Flow Rates of CeO_2/waterNanofluid on Efficiency

For a flat plate solar water heating system, the efficiency may be defined as the ratio of the output energy given by the solar collector to the input energy supplied by solar radiation which is one of the most important deciding parameters. The efficiency is also determined by various other parameters like intensity of solar radiation falling on the solar collector, typeof working nanofluid, particle size of the nanoparticle, volume concentration, inlet temperature of nanofluid and ambient temperature. Figure 7 shows the variationofinstantaneouscollectorefficiencyversusreducedtemperature parameter $(T_i–T_a)/G_T$ for CeO_2/water nanofluid with the volume concentration of 0.01% by varying the volume flow rates from 1 to 3 Lit/min representing experimental analysis. The experimental data which has all the volume flow rates are fitted with linear trend line equations for describing characteristic parameters of flat plate solar water heater. It is seen from the Figure 7 that CeO_2/water nanofluid with the volume concentration of 0.01% at the volume flow rate of 2 Lit/min gives maximum efficiency of 78.2% for experimental analysis. It is also observed that the trend lines with respect to 1 Lit/min and 3 Lit/min volume flow rates intersect at reduced temperature parameter $(T_i – T_a)/G_T$ having a value of 0.018.It is due to the operating of solar collector which willnot bethat much effective when thereduced temperatureparameter $(T_i–T_a)/G_T$ is greater than 0.018 in case of 3 Lit/min. After which theefficiency of flat plate solar water heater gets reduced when compared to 1 Lit/min volume flow rate. The flat plate solar water heater efficiency parameters such as energy absorbed parameter $F_R(\tau\alpha)$ and removed energy parameter of F_RU_L have been tabulated for all the volumeflow rates of working nanofluid. It is seen that the instantaneous solar water heater efficiency for CeO_2/water nanofluid operating at 2 Lit/min is 78.2% which is higher when compared with the efficiency of the collector operatingat other two volume flow rates. When the collector is operated by varying the volume flow rate from 1 to2 Lit/min, the efficiency of solar water heater get improved by about 10.86% while it is reduced byabout 5.62% when the solar water heater is operated with volume flow rate of 3 Lit/min. At higher volume flow rates, the temperature rise in theworkingfluid itselfis smalldue to lesser residence time of nanofluids in the heat exchanger thereby less heat transfer rate. It is also seen that collector efficiency increases with the increase in volume flow rate up to 2 Lit/min after which it shows negative results.

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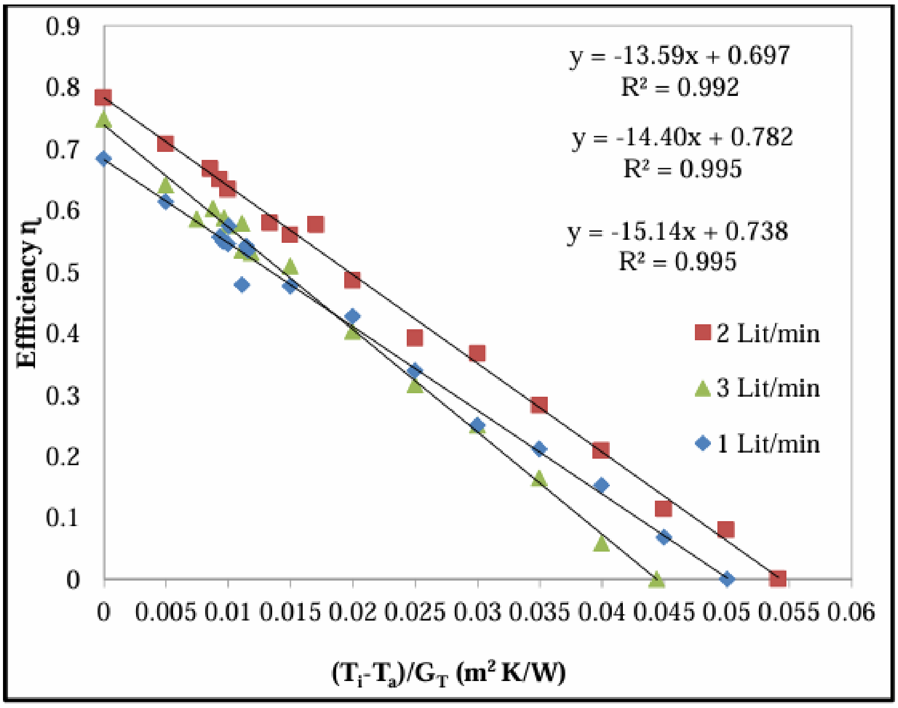

Figure 7 EfficiencyofCeO$_2$/waternanofluidat0.01%volume concentration

Figure 8 shows thevariation ofinstantaneous solar waterheater efficiencyversusreducedtemperatureparameter(T_i–T_a)/$G_T$forCeO$_2$/water nanofluid with the volume concentration of0.05%byvaryingthe volume flow rates from 1 to 3 Lit/min. It is observed from Figure 8 that the trend lines with respect to 1 Lit/min and 3 Lit/min intersect at reduced temperature parameter (T_i –T_a)/G_T having a value of 0.020. The similar trend was also observed in the case of 0.01% volume concentration. It shows that the operating of solar water heater will not be that much effective when the reducedtemperatureparameter(T_i–T_a)/$G_T$isgreaterthan0.020incaseof3 Lit/min after which the efficiency of solar water heater gets decreased when compared to 1 Lit/min volume flow rate. The solar water heater efficiencyparameters of $F_R(\tau\alpha)$ and $F_RU_L$have been tabulated for all the volume flow rates of working nanofluid. It is seen from the Figure 8 that CeO$_2$/water nanofluid with the volume concentration of 0.05% at the volume flow rate of 2 Lit/min gives maximum efficiency of 81.2% for experimental analysis while it is 74.9% and 78.9 % at the volume flow rate of 1 Lit/min and 3 Lit/min respectively. It is interesting to see that when the volume flow rate is increased from 1 to 2Lit/min, there is a gradual increasein the efficiency but further increase from 2 to 3 Lit/min there is a gradual decrease in the efficiency of the solar water heater.As per equation 6.4, the energy absorbed parameter $F_R(\tau\alpha)$ is dominant in the region of lower temperature differences while the removed energy parameter F_RU_L is

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dominant in the region of higher temperature differences. When the solar water heater is operated at 2 Lit/min, the time of circulation of the nanofluids in the collector is higher and hence greater absorption of solar energy which leads to more temperature rise in the solar water heater thereby higher heat transfer rate.

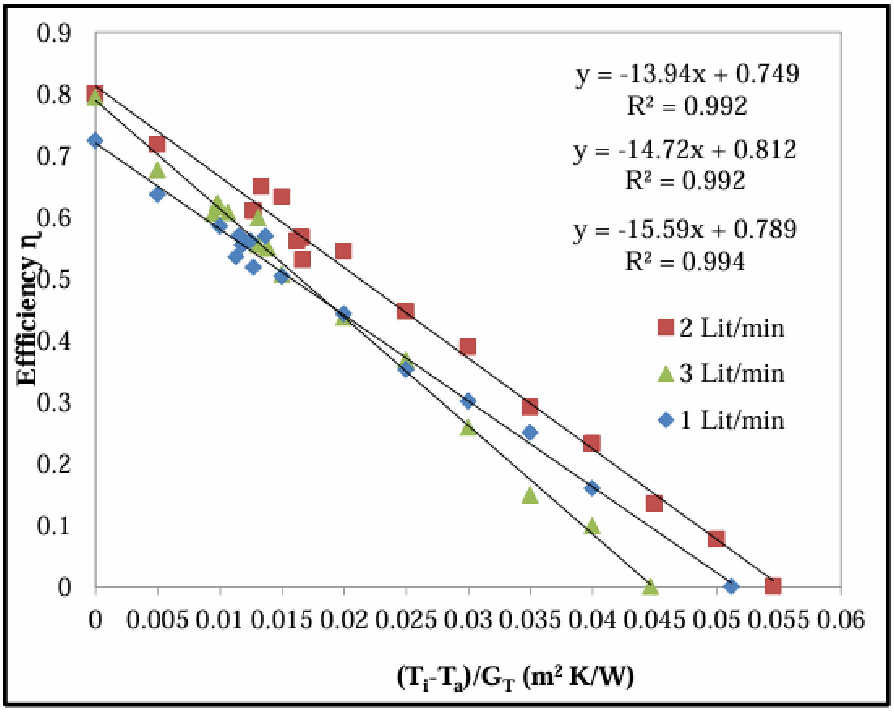

Figure 8 EfficiencyofCeO2/waternanofluidat0.05%volume concentration

4. Conclusion

Experimental investigations demonstrated that CeO_2/water nanofluid significantly enhances the thermal performance of flat plate solar water heating systems compared to conventional base fluids. The maximum collector efficiency of 81.2% was achieved at 0.05% volume concentration and a flow rate of 2 L/min, beyond which efficiency decreased due to limited heat absorption time. The results also confirmed that the thermal stratification within the storage tank improved energy retention and system stability.Furthermore, the CeO_2/water nanofluid exhibited higher thermal conductivity and effective heat transfer characteristics than Al_2O_3/water nanofluid, emphasizing its potential for cost-effective solar thermal applications. The findings reinforce that nanofluid-based collectors, when optimized for flow rate and concentration, can substantially increase solar utilization efficiency and contribute to sustainable heating solutions for domestic and commercial purposes. Future studies may explore long-term stability, scaling resistance, and hybrid nanofluids to further improve collector performance.

References

[1] Glembin, J., and Rockendorf, G. (2012). Effects of different discharging and charging strategies and their effects on the performance of a combined solar thermal system. Solar Energy, 86, 611–620.

[2] Chong, K.K., Lau, S.L., and Wong, C.W. (2012). Stationary V-trough solar water heating system with simulated solar concentration. Renew. Energy, 47, 9–15.

[3] Bellamy, D. (2023). Energy performance evaluation of solar-heated stratified concrete wall panels. Energy Build., 55, 35–42.

[4] Sarver, T., Al-Qaraghuli, A., and Kazmerski, L.L. (2024). Environmental and climatic influences on collector efficiency. Renew. Sustain. Energy Rev., 28, 145–159.

[5] Nwosu, P.N., Al-Kayiem, H.H., and Jameel, M. (2013). Development of a low-cost fibre-reinforced plastic hot-water storage tank for solar collectors. Energy Convers. Manage., 76, 1054–1062.

[6] Hobbi, A., and Siddique, M. (2025). Optimal design of forced-circulation solar water heating systems for cold climates using TRNSYS. Renew. Energy, 34, 25–34.

[7] Dickinson, R.M., Taylor, J.A., and Davies, R.W. (2024). Thermal behaviour of stratified tank systems under constant-temperature charging using TRNSYS. Appl. Therm. Eng., 54, 62–70.

[8] Chen, L., Zhang, X., and Yang, Z. (2021). Heat-transfer behaviour of a two-phase thermosyphon using CO_2 in the supercritical region. Appl. Therm. Eng., 61, 456–463.

[9] Masuda, H., Ebata, A., Teramae, K., and Hishinuma, N. (1993). Alteration of thermal conductivity and viscosity of liquid by dispersing ultra-fine particles. Netsu Bussei, 7(4), 227–233.

[10] Eastman, J.A., Choi, S.U.S., Li, S., Yu, W., and Thompson, L.J. (2017). Enhanced thermal conductivity through development of nanofluids. Appl. Phys. Lett., 78(6), 718–720.

[11] Hwang, Y., Lee, J.K., and Jung, W.H. (2021). Thermophysical behaviour of Al_2O_3/water nanofluids for heat-transfer enhancement. Int. J. Heat Mass Transf., 44, 865–872.

[12] Das, S.K., Choi, S.U.S., Yu, W., and Pradeep, T. (2003). Nanofluids: Science and Technology. Wiley, New York.

[13] Lee, S., Choi, S.U.S., Li, S., and Eastman, J.A. (2008). Measuring thermal conductivity of fluids containing oxide nanoparticles. J. Heat Transf., 121, 280–289.

[14] Zhu, H., Zhang, C., and Lin, Y. (2008). Preparation and thermal conductivity of Al_2O_3 nanofluids. Curr. Appl. Phys., 9, 102–108.

[15] Pastoriza-Gallego, M.J., Lugo, L., and Piñeiro, M.M. (2009). Thermophysical properties of Al_2O_3/water nanofluids. Nanoscale Res. Lett., 4, 143–152.

[16] Teng, T.P., and Hung, Y.H. (2014). Effect of nanoparticle size on thermal conductivity of Al_2O_3/water nanofluids. Appl. Therm. Eng., 73, 1–8.

[17] Wen, D., and Ding, Y. (2005). Effective thermal conductivity of nanofluids containing oxide nanoparticles. J. Thermophys. Heat Transf., 19(4), 718–726.

[18] Omid, M., Farzaneh, H., and Javad, T. (2014). Heat-transfer analysis of nanofluid flow in solar-thermal collectors. Energy Convers. Manage., 88, 555–563.

[19] Yousefi Tooraj, T., Veysi, F., and Karimi, S. (2012). Experimental investigation on the efficiency of flat-plate solar collectors with nanofluid. Renew. Energy, 39(1), 293–298.

[20] Gangadevi, R., and Subramanian, S. (2013). Enhancement of solar-collector performance using nanofluids. J. Therm. Sci., 22(4), 345–351.

[21] Hemant Kumar Gupta, H.K., and Agrawal, G.D. (2015). Experimental studies on solar water heaters using Al_2O_3/water nanofluid. Energy Procedia, 79, 212–219.

[22] Gianpiero Colangelo, G., Favale, E., and Milanese, M. (2015). Performance analysis of nanofluid-based flat-plate solar collectors. Energy, 82, 678–689.