

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

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## Abstract

*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 copper oxide (CuO) nanofluid at 18l/min. 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 0.015vol CuOnanofluid with a higher rate of flow, proving better thermal performance and offering a maximum temperature gain of 68°C with a better heat transfer coefficient of 81.5W/m<sup>2</sup>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.*

**Keywords:** Copper oxide; Heat pipe solar absorber; Nanofluid; Thermal performance.

## **1. Introduction**

In a recent scenario, the energy gathered from renewable sources was significantly up-trend, and the contribution of renewable solar energy increased in different engineering applications [1]. The uniqueness of solar air heaters adopted for food, textile, space heating, 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 collectors by 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 (copper oxide, alumina and titanium oxide particles) on the thermal performance of solar collectors configured with heat pipe flat plates was experimentally evaluated by different flow rates and reported that copper oxide (CuO) based nanofluid offered maximum thermal performance related with water fluid and improved collector efficiency as 2.95% [12]. Henein et al. [13] studied the thermal characteristics of the heat pipe and tube solar collector adopted with magnesium oxide (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/min 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, MgOnanofluids 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 8pipes assembly was enhanced by using alumina ( $Al_2O_3$ )/water and titanium dioxide ( $TiO_2$ ) /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 setup. Likewise, Venkatesh et al. [18] reported that the solar absorber properties were enhanced by a higher flow rate ( $0.0316kg/sm^2$ ). Dehaj et al. [19] experimentally evaluated and studied the performance of copper oxide (CuO) nanofluid adopted heat pipe solar collector under different volume concentrations of CuO at a varied flow rate of 8 and 14l/min and found that the 0.008 vol. fraction found to be better thermal efficiency of 80% at a higher flow rate of 14l/min. However, the thermal management system will be adopted to monitor solar performance conditions [20].

From the above 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 CuOnanofluid with concentrations of 0.005, 0.01, and 0.015volume 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.

## **2. Materials and methods**

### **2.1 Details of materials**

In the group of nanofluids, copper oxide (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 CuOnanofluid are addressed in Table 1.

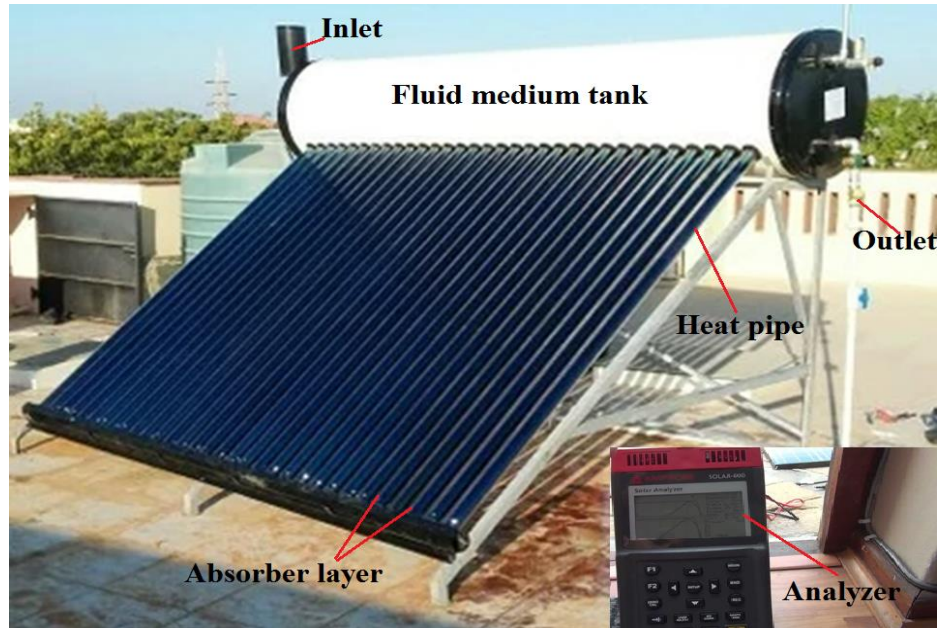
**Table. 1 Characteristics of water and CuOnanofluid**

S.No	Properties of fluids	Unit	Fluid medium	
			Water	CuOnanofluid
1	Density ( $\rho$ )	kg/m <sup>3</sup>	997.77	6315
2	Thermal conductivity (K)	W/m.K	0.598	18
3	Specific heat (C <sub>p</sub> )	J/kg.K	4179	540

## 2.2 Experimental details

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

The water is filled in the storage tank and circulated at different flow rates of 18l/min. Monitored the temperature variations from 8.00am to 6.00pm 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.



**Figure. 1 Actual setup of heat pipe solar absorber with the solar analyzer**

The experimental study is executed with (i) water fluid medium, (ii) 0.01volume concentration of CuOnanofluid, (iii) 0.015volume concentration of CuOnanofluid, and (iv) 0.020volume concentration of CuOnanofluid on 18l/min flow rate on temperature gain, heat transfer coefficient, and thermal efficiency of heat pipe solar absorber are evaluated and compared.

**Table. 2 Specification of heat pipe solar absorber**

S.No	Descriptions	Units
1	Diameter of pipe	40mm
2	Thickness	3mm
4	Diameter of glass cover	50mm
5	No of pipes	30nos
6	Length of pipe	1700mm
7	Material	Aluminum
8	Nanofluid used	water and CuO
9	Distance between two tubes	50mm

### 2.3 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 Table 3.

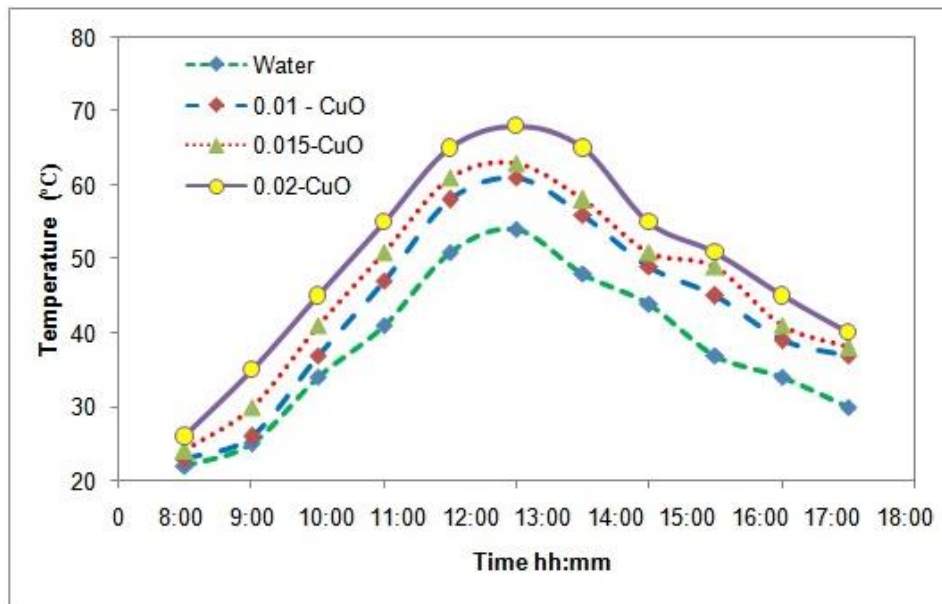
**Table. 3 Uncertainty analysis**

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

### 3. Results and discussions

#### 3.1 Temperature gain

Fig. 2 presents the variations in temperature of fluid medium noted with their effect of heat pipe solar absorber operates with water and CuOnanofluid under 18l/min flow rate.

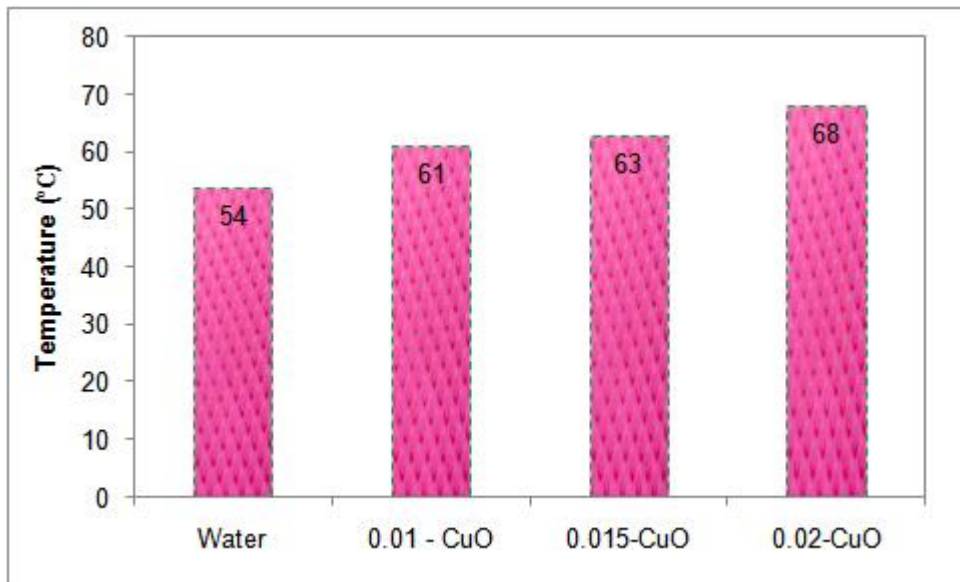


**Figure. 2 Variations in temperature gain of fluid on heat pipe solar absorber**

Here, the system of fluid temperature is noted every hour from 8.00am to 6.00pm for five days. The temperature gain of HPSA operated with water and CuOnanofluid at different volume fractions showed that the temperature steadily improved up to 1.00pm. Afterwards, the

temperature showed a gradual downtrend. Besides, the temperature gain of CuO-concentrated nanofluid is higher than that of the water fluid medium. Earlier, Henein et al. [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°C to 54° between 8.00am to 1.00pm and gradually decreases to 30 at 6.00pm. 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 CuOnanofluid at 18l/min flow rate offered a maximum temperature gain of 68°C at 1.00pm. The temperature enhancement was due to the CuOnanofluid [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 18l/min 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 (1.00pm) is detailed in Fig. 3.



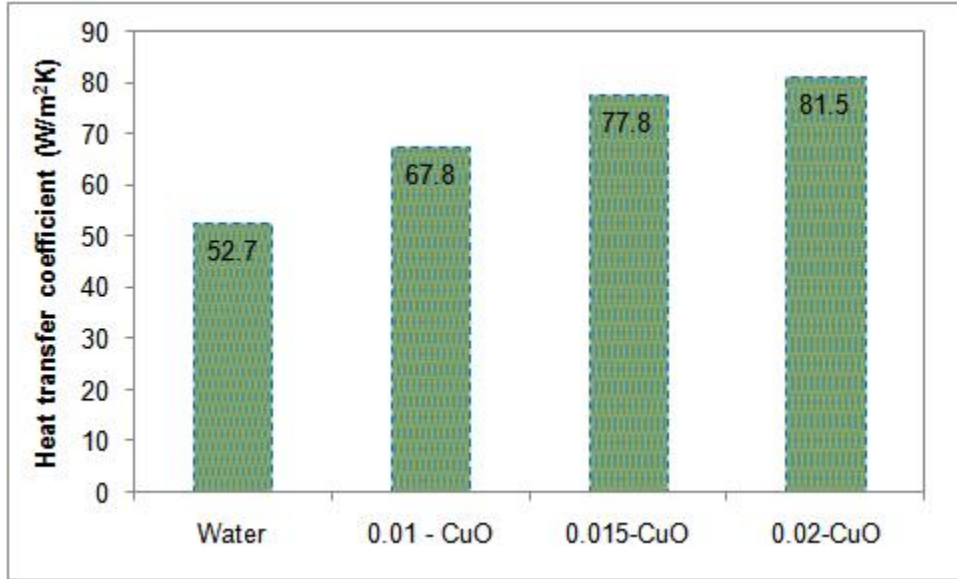
**Figure.3 Temperature gain measured by solar peak time (1.00pm) at 18l/min**

### **3.2 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 be 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**

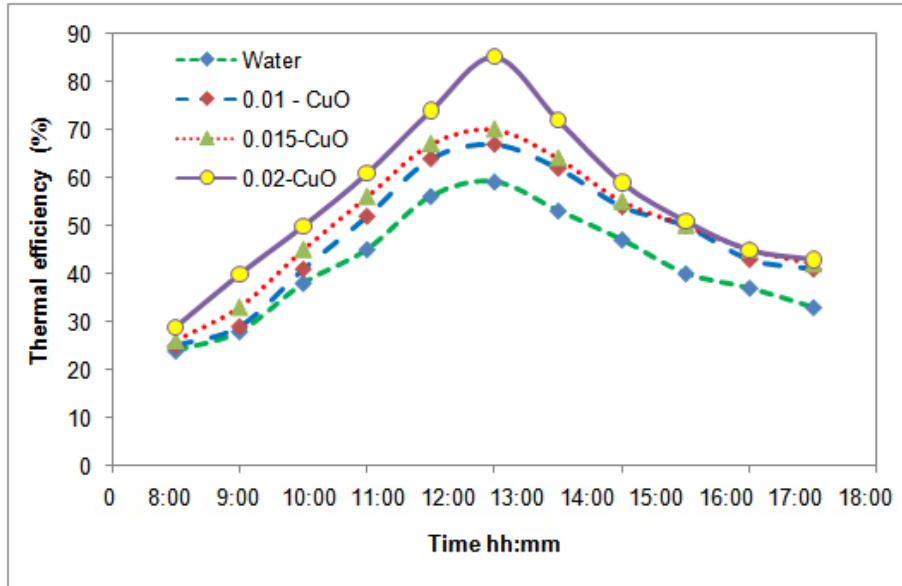
Here, the heat pipe solar absorber investigated with water fluid showed the nominal amount of heat transfer coefficient ( $52.7\text{W/m}^2\text{ K}$ ), and the experiment carried with 0.010 volume fraction of CuO nanofluid was found to be  $67.87\text{W/m}^2\text{ K}$  because the thermal conductivity 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  $81.57\text{W/m}^2\text{ K}$  on 0.020 volume concentration of CuO nanofluid operated at 18l/min, 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].

### 3.3 Thermal efficiency

Fig. 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, CuOnanofluid 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 1.00pm after it was a downtrend. Specifically, the HPSA with 0.010, 0.015, and 0.020 volume fractions of CuOnanofluid has 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 CuOnanofluid executed with an 18l/min 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, Table 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**

Nano Fluid	Thermal efficiency	Reference no
MgO/MWCNT (50/50)	77.14	13

MgO/water (0.014vol)	72.4	14
TiO <sub>2</sub> /water (2%)	64	16
CuO/water (0.017vol 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 18l/min 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, 21-24].

#### 4. 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 CuOnanofluid 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.

- 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°C at noon.
- Likewise, the heat transfer coefficient of 0.020 volume fraction of CuOnanofluid was maximum (81.5W/m<sup>2</sup>K), hiked by 55% related to water fluid medium.
- Similarly, the thermal efficiency on 0.02 volume fraction of CuOnanofluid operated heat pipe solar absorber observed higher solar efficiency of 85.2% at 18l/min.
- 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

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