Thermal Performance of Evacuated Tube Solar Collector using Water and CuO/Water Nanofluid

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ABSTRACT

This paper describes an experimental study of a heat pipe evacuated tube collector (ETC) with water and CuO/Water nanofluid (CWNF) for water heating application. In this study, the work is divided into three parts: fabrication of thermal system, preparation of CuO/water based nanofluids and performance analysis of thermal system. In the same parameter, a comparison of two systems was performed. Water was left in the evacuated tubes of the first system, and the second system integrated with CuO/water. The experiment was carried out with two distinct water flow rates (0.012 kg/s and 0.018 kg/s) in order to examine the thermal performance of the developed systems. For water flow rates of 0.012 kg/s and 0.018 kg/s, thermal energy efficiency of evacuated tube collector integrated with CWNF was 35.04% and 33.20%, respectively, compared to ETC with water. By improving the performance of ETC, the size of the thermal system might be reduced by 25.95%.

Keywords: Solar Energy, Solar Collectors, Renewable Energy, Evacuated Tube, Evacuated Tube Collectors, Heat Pipe

1 Introduction

Energy is very essential for the development of human life. Now a day's in human life, it plays a key role. So, day after day the demand of energy is growing. Non-conventional source of energy is cheap and best for environmental point of views because by using these energy resources it emits less carbon emission. Solar energy is the most effective non-conventional energy source. The sun is the primary source of solar energy. Solar energy is utilised by the collector is called solar collector. There are two kinds of solar collectors. One is concentrating type solar collector and another one is non-concentrating. The performance of the solar collector is very low so efficient working fluid must be used to enhance its performance. Improving its performance can help reduce the size of the power system. To make the working fluids more efficient nanotechnology is used. By using the Nanotechnology in solar collector, the efficiency and the performance is increased. The advanced form of solar collector is the ETC for their good thermal insulation characteristic and its geometry. In the ETC there are two concentric cylinders. Between the cylinders vacuum is place. The reason of placing the vacuum is to reduce the conventional heat losses. Inner cylinder is coated with selective coating so that it absorbs more solar radiation.

Solar collectors are devices that harvest solar energy and by some arrangement solar energy can be converted in other forms of energy very easily. The main limitations of solar collectors are its efficiency. Solar collectors have a quite low efficiency. By Improving its performance can help minimise the power system's size (Gupta & Prasad, 2020). By using nanotechnology in solar collectors, the efficiency and performance of the working fluids are increased. Because of its good thermal insulation and shape, ETC is the most sophisticated type of solar collector. The ETC consists of two concentric cylinders. Vacuum is inserted between the cylinders. The hoover is used for minimising conventional heat losses. (Choi, 1995)

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introduced the concept of nanofluid in solar collectors. (Natarajan & Sathish, 2009) used nanofluid in solar water heaters and found that by using nanofluid the performance of the water heaters is improved. (Tyagi et al., 2009) and (Mahendran *et al.*, 2012) used Al_2O_3/water and TiO_2/water nanofluid for their collector system and found that using nanofluid as working fluids enhanced the performance of collector by 10% and 16.7% respectively as compared to normal conventional fluids. (Chopra *et al.*, 2020) used PCM in solar collectors to improve their performance.

2 Materials and Experimental Setup

In this work, the first part shows the preparation of CWNF, and the second part shows CWNF performance with ETC from an experimental point of view. The CuO nanoparticles are purchased from the supplier. The shapes of the nanoparticles are spherical, and their purity was 99.9% as claimed by the supplier. Table 1 displays the properties of CuO Nanoparticles and Conventional Base Fluid Water.

Table 1: *Properties of CuO Nanoparticles & Conventional Base Fluid Water*

	Properties			
	Specific Heat Capacity	Density	Thermal conductivity	Viscosity
	joule/kg-℃	kg/m^3	W/m-k	m^2/s
CuO Nanoparticles	531	6000	33	--
Conventional Base Fluid Water	4186	1000	0.6	0.0000017

2.1 Preparation of Nanofluid

For the preparation of nanofluid, two step-method has been used. Firstly, by a chemical process, nanoparticles were prepared and it is purchased from supplier. Then amount of the nanoparticles was calculated as, was mixed with the base fluid, water. Initially, 0.05% volume fractions of nanoparticle were mixed in water.

For better dispersion of solid nanoparticles with the fluid, the mixture was stirred. Further, for proper dispersion of CuO nanoparticles with water, an ultrasonic cleaner with a magnetic stirrer was applied for to ensure no agglomeration in the solution. Again, by using a magnetic stirrer the solution was mixed properly. The stability of the CWNF was checked through the naked eye. Figure 1 shows the process of nanofluid preparation.

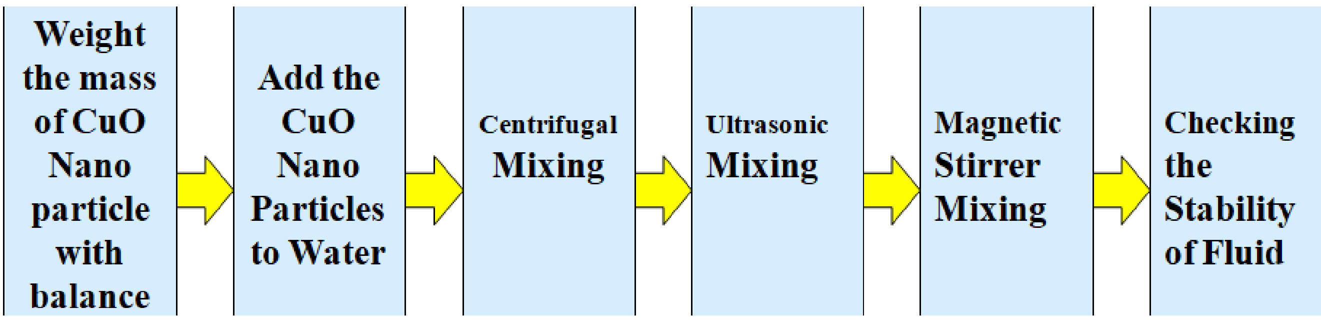


Figure 1: *Process of CWNF Preparation*

The NWNF density, specific heat capacity, viscosity, and thermal conductivity were 1250 kg/m^3, 3207.61 joule/ (kg-℃), 0.0000028 m^2/s, and 0.6895 W/m-k, respectively.

2.2 Experimental Setup

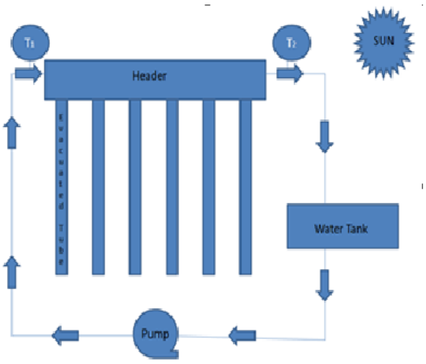


Figure 2: *Diagram of the Experimental Setup*

The experiment was performed at Mechanical Engineering Department, MMMUT, Gorakhpur. The experiment was carried out in 12-time intervals for two days. Each time intervals were for 1 hour. All the reading was taken under steady-state conditions. Figure 2 shows the setup of ETC with CWNF. 15 ETC were used at an inclination angle of the setup is 27 degrees. There were two loops in the equipment. In the first loop, the working fluid flows through an evacuated tube and gets heated by absorbing solar energy. In the second loop, water flows through the header which acts as a heat exchanger. Table 2 shows the specification of the setup of the ETC.

Table 2: *Specification of the setup of the ETC*

Specifications			
Length	Width	Height	Gross area
(mm)	(mm)	(mm)	(mm^2)
1150	1160	950	1150 x 1160

The total volume of the ETC was 21.64 *lt*, which was considered as the quantity of the liquid space capacity. The gross area of the collector was 3.18 m^2. The area of ETC where the solar radiation falls is called the aperture area of the collector. It is calculated as half of the gross area of the collector, which was 1.59 m^2.

Evacuated Tube is the most important component of the ETC. Table 3 has an overview of the evacuated tube.

Table 3: *Specification of Evacuated Tube*

Specifications								
Length	Inner Diameter	Outer Diameter	Number of tubes	Liquid space capacity	Aperture area	Gross area	Absorber absorption coefficient	Absorber emission factor
(mm)	(mm)	(mm)	(Nos.)	(*lt*)	(m^2)	(m^2)		
1150	1160	950	15	21.64	1.59	3.18	0.93	0.08

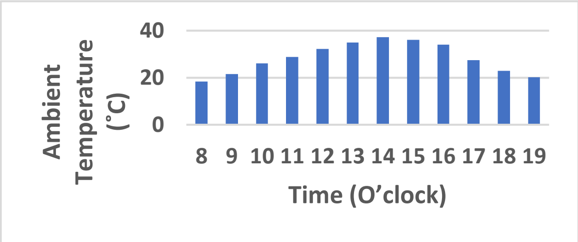
3 Results and Discussion

ETC Performance Using Water and CWNF as Working Fluid

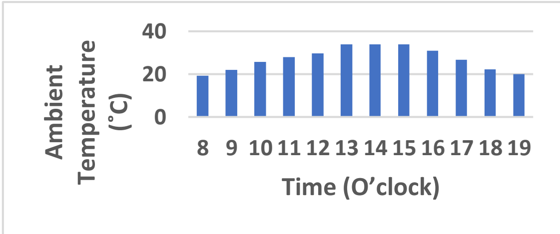
The experiment was done on the 1-hour time intervals and the results found are discussed below.

3.1 Recorded Ambient Temperature

For both the working fluids, the ambient temperature increased from morning to noon, and after attaining a peak, it started to decrease in the evening. Figure 3 is showing the graphs between times Vs ambient temperature for water and CWNF respectively.



(a)

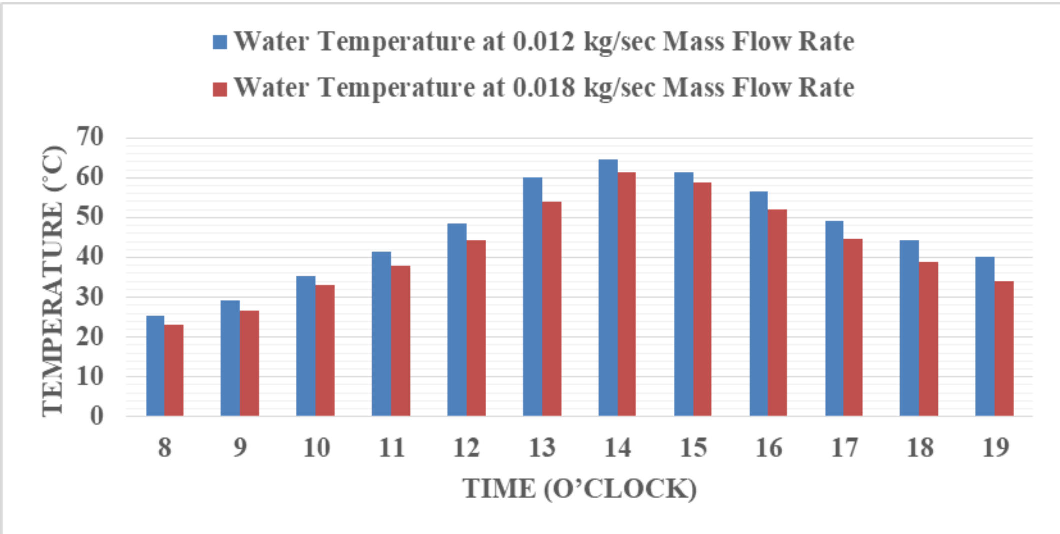


(b)

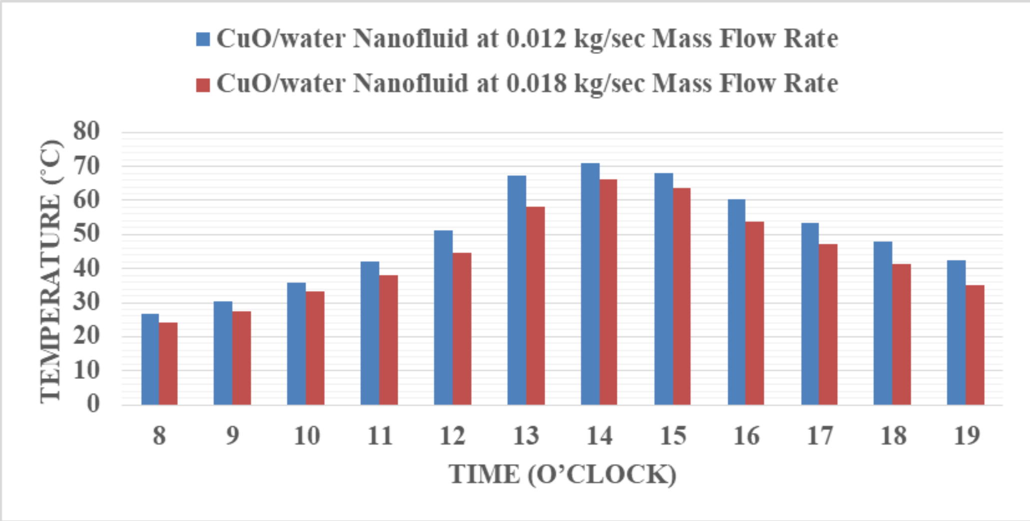
Figure 3: *Recorded Ambient Temperature for (a) water & (b) CWNF as the working fluid respectively*

3.2 Comparison of Water Temperature at Mass Flow Rate (MFR) 0.012 and 0.018 kg/s

In both cases, in the second loop, the MFR increasing, and the temperature of working fluid water was decreasing. Due to the increasing rate of MFR, the heat transfer rate got slowed down and that's why there was a fall in the temperature of the working fluid. Also because of the contact time of flowing fluid, water in the header decreased. Figure 4 is showing the comparison of water temperature with time at MFR of 0.012 and 0.018 kg/s for water and CWNF respectively.



(a)

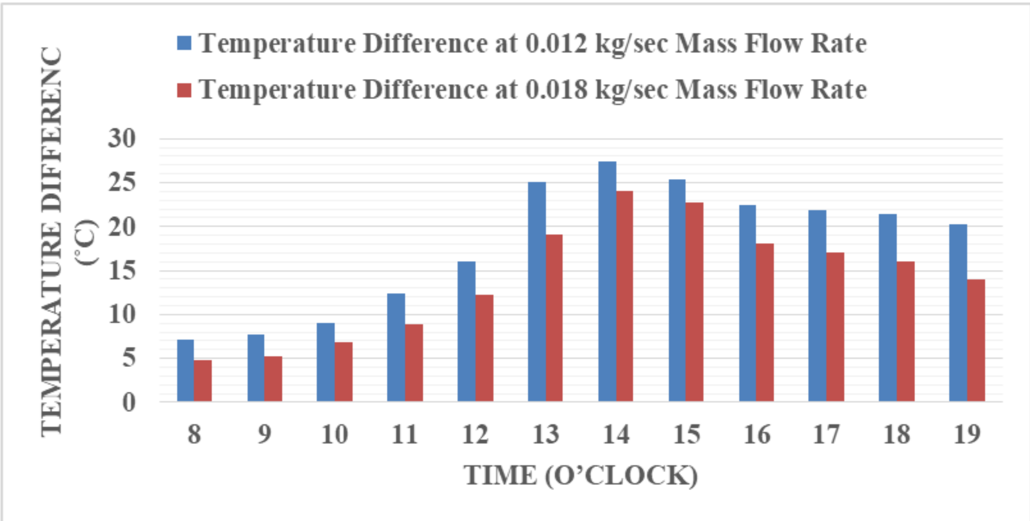


(b)

Figure 4: *Comparison of Water Temperature at Various MFR 0.012 and 0.018 kg/s for (a) water & (b) CuO/Water Nanofluid as the working fluid*

3.3 Comparison of Temperature Difference between WaterTemperature and Ambient Temperature at MFR 0.012 and 0.018 kg/s

Again, similarly in both cases, in the second loop, the MFR was increasing, the temperature difference of the working fluid wrt. The ambient temperature was decreasing. Also due to the increasing MFR, the heat transfer rate got slowed down, and the temperature difference wrt. the ambient temperature of the working fluid decreased. Figure 5 is showing the comparison of the temperature difference between water temperature and ambient temperature at 0.012 and 0.018 kg/s MFR for water and CWNF respectively.



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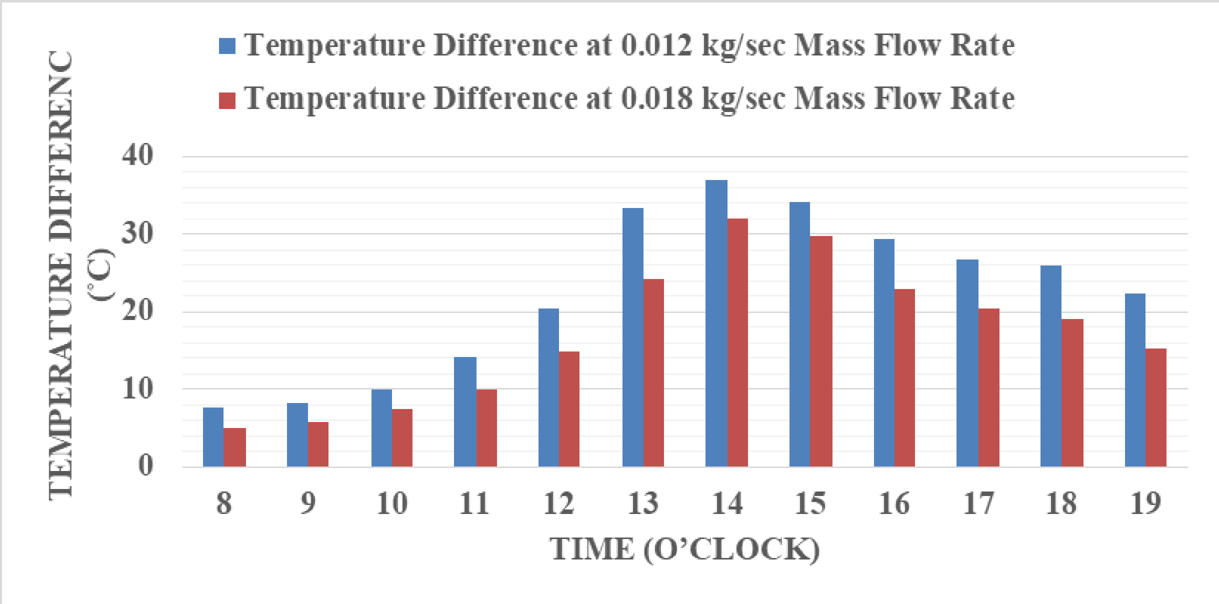

(b)

Figure 5: *Comparison of Temperature Difference between Water Temperature and Ambient Temperature at MFR 0.012 and 0.018 kg/s for (a) water & (b) CuO/Water Nanofluid respectively*

3.4 Comparison of Performance of ETC Using Water and CWNF as Working Fluid at MFR 0.012 and 0.018 kg/s

After collecting the experimental data from ETC using water and CWNF as working fluid, the comparison of the thermal performance of the ETC using conventional working fluid water and the CWNF was analysis.

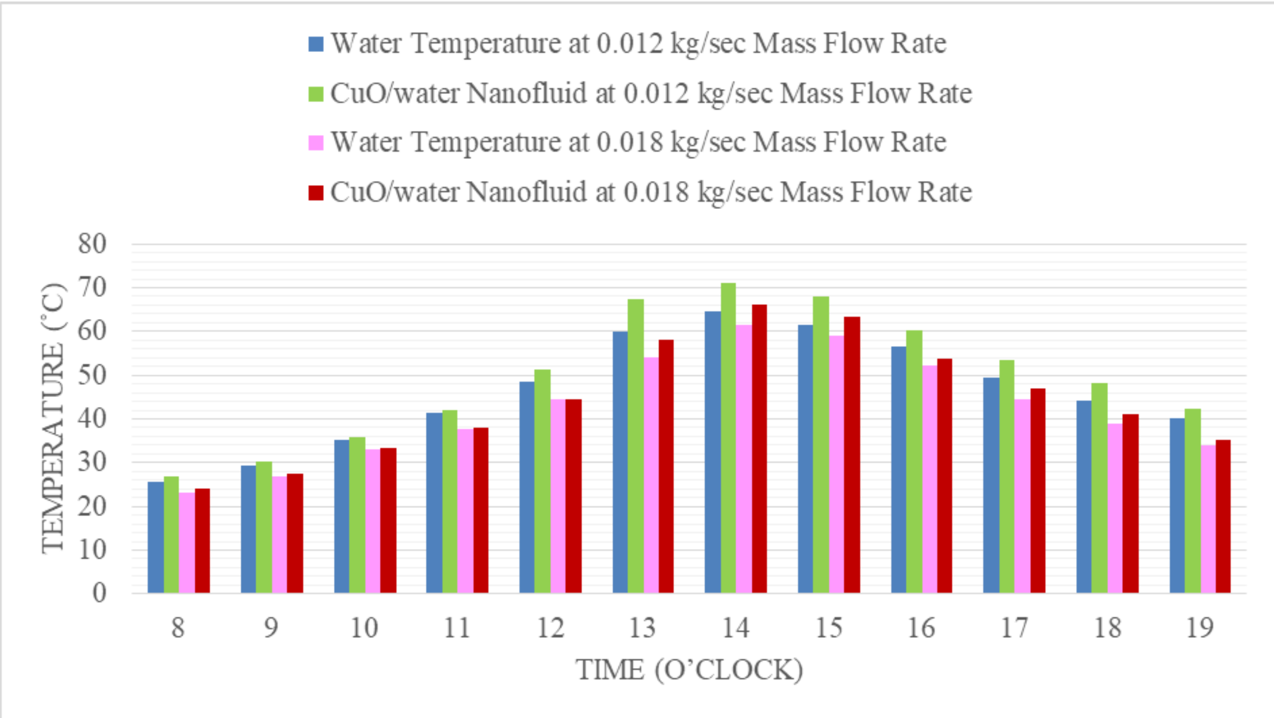

Figure 6: *Performance Analysis of ETC using Water and CuO/Water Nanofluid*

The performance of ETC was measured on the basis of the percentage increase in the temperature difference of water and CWNF at 0.012 and 0.018 kg/s mass flow rates. Figure 6 shows the resulting graph, which tells that the temperature difference between flowing fluid and ambient temperature at 0.012 kg/sec at 14.00 o'clock is the maximum.

CWNF performance was 35.04% and 33.19% higher compared to water in an optimal condition, hence, the solar collector area was reduced by up to 25.94% and 24.91% at 0.012 kg/s and 0.018 kg/s rates of mass flow respectively. Therefore, it is also clear that the performance of ETC using CWNF is more than the ETC using water because the temperature difference is more in CWNF as compared to the water. The CWNF increases the thermal conductivity of the fluid so that it attains a uniform temperature inside the whole fluid domain. The main concept behind the nanofluid is it is the combination of nanoparticles and the base fluids water and the thermal conductivity of the solid is more than the liquids.

4 Conclusions

From this experiment, it's cleared that working fluids clearly influence the performance of ETC. The thermal performance of ETC using nanofluid is more as compared to the water. The performance of an ETC is also depending on its MFR. The performance of the ETC decreases as the rate of mass flow increases. It was also observed that the collector area performs an essential role in the performance of ETC. Increasing in performance of the evacuated tube collector can reduce the collector area.

The high cost of the evacuated tube and CuO nanoparticles caused the high cost of the experiment. The evacuated tubes are very brittle in nature. So, safety of the evacuated tube is very essential. The concentration of the nanofluid determines its thermal conductivity. But by increasing the concentration percentage of nanofluid, it will start getting sedimented rapidly in the base fluid.

Nanotechnology is an advanced field in the application of solar energy. The usage of nanofluid improves solar collector performance. The experimental work is expensive; hence performance analysis of ETC with nanofluid can be done using numerical method.

5 Declarations

5.1 Competing interests

No conflict of interest exists.

5.2 Publisher's Note

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How to Cite

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