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Performance Augmentation of Solar Evacuated Thermal Collector Using Hybrid Nanofluid

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Abstract

The performance of solar evacuated thermal collector (SETC) was investigated by using water-based aluminum oxide (Al_2O_3) nanofluid and combination of Al_2O_3 and copper oxide (CuO) hybrid nanofluid. The influence of several parameters namely, fluid outlet and inlet temperature, nanofluid volume fraction, and ambient temperature on the collector performance was investigated. The fluid properties such as specific heat, viscosity, density, and thermal conductivity of the working fluid were estimated using correlations from the literature. The experimental work was carried out on SETC with pure water initially and later with nanofluids. The flow rate in the tube was fixed at 5 LPH and 8 LPH and the observations were noted several times in a sunny day to study the thermal performance. The experimental results revealed that higher volume fraction of Al_2O_3 nanofluid yield higher efficiency. The energy efficiency also increases with higher solar radiation intensity. Using hybrid nanofluid (Al_2O_3 + CuO), maximum collector efficiency of 84.23% and 94.78% were noted for 0.01 and 0.03 volume fractions at 8 LPH flow rate.

Keywords

Evacuated tube, Thermal collector, Collector performance, Hybrid nanofluid

Introduction

The research work on nanoparticles application in industry was on rise in the recent years due to their outstanding ability to enhance the thermophysical properties of working fluids. Abundant research was carried out in the area of characterization and synthesis of nanoparticles and their dispersion for several applications. The more prevalent method noticed was the disruption of agglomerated nanoparticles to produce nanofluid [1]. The thermal performance improvement of thermal collectors was the prime concern in solar energy utilization and equipment design. The use of additives in the base fluid was one among the innovative techniques employed to enhance the thermal performance [2-4]. The suitability of nanofluids to augment heat transfer in heat exchangers was investigated experimentally and by numerical methods [5].

The influence of heat exchanger geometry on thermal performance was revealed; that with the addition of nanoparticles in the working fluid, the fluid flow changes to turbulent at a low Reynolds number and thus increases the hydraulic impact than the thermal impact. Several research studies on heat exchanger performance [6-8] show that the addition of nanoparticles the conventional base fluids enhances thermal performance but has a drawback of high-power consumption for pumping nanofluid. The thermal performance of a shell tube heat exchanger was investigated using hybrid nanofluid containing graphene multi-walled carbon nanotubes [9]. The results indicated a 23% increase in overall heat transfer coefficient and the heat transfer rate. Sabiha et al. [10] presented the work on performance enhancement of evacuated tube heat pipe solar collector using SWCNT nanofluid. They conducted experiments with three different volume fractions 0.05, 0.1, and 0.2 and at different mass flow rates. The results indicated maximum efficiency of 93.43% with 0.2 SWCNT volume fraction at 0.025 kg/s flow rate.

Hussain et al. [11] utilized nanofluid in their work to enhance the efficiency of an evacuated tube thermal collector. Two different nanoparticles, zirconium oxide (ZrO_2) and silver (Ag) with 50 nm and 30 nm, respectively, was dispersed in water with 0.01, 0.03, and 0.05 volume fraction. They prepared the nanofluid by using a two-step technique and thus, an attempt was made to examine thermal efficiency of the collector using ZrO_2 and Ag nanoparticles with different volume fraction at 30 and 90 LPH. Their results indicated that, due to higher thermal conductivity, the thermal efficiency of the solar collector using 5% Ag nanofluid was higher compared to 5% ZrO_2 nanofluid. The hybrid nanofluid containing the two different nanoparticles was effectively distributed in the fluid medium. The hybrid nanofluid was prepared with a sole purpose of improving the thermophysical properties of the working fluid in the collector.

Since the use of Al_2O_3 + CuO hybrid nanofluid was found to be sparse in the literature, in the present work it was considered for the performance investigation of a solar thermal collector. The experiments were conducted using an evacuated tube thermal collector with pure water initially and later with Al_2O_3 nanofluid and also with a combination of Al_2O_3 + CuO (50% each) hybrid nanofluid for varying mass flow rate. The readings were noted at regular time interval in a daytime and the flow rate in the tube collector was fixed at 5 LPH and 8 LPH during the trials.

Methodology

Preparation of nanofluid

The Al_2O_3 nanoparticles (47 nm) were procured from Sigma-Aldrich Chemicals, USA is shown in figure 1, and then nanofluid was prepared with pure water as base. The measure of nanoparticles for the most used volume fraction was estimated from the equations mentioned below.

$$\text{Volume fraction, } \phi \times 100 = \left[\frac{Volume\ of\ Al_2O_3}{Volume\ of\ Al_2O_3\ +\ Volume\ of\ water} \right] \quad (1)$$

$$\text{Volume fraction, } \phi \times 100 = \left[\frac{\left(\frac{Weight}{Density}\right)_{Al_2O_3}}{\left(\frac{Weight}{Density}\right)_{Al_2O_3} + \left(\frac{Weight}{Density}\right)_{base\ fluid}} \right] \quad (2)$$

Where, ϕ indicates the percentage of volume fraction, $W_{Al_2O_3}$ represent the nanoparticle mass density (3970 kg/m^3), $W_{basefluid}$ represent the base fluid weight (100 g), and $W_{Al_2O_3}$ represent the Al_2O_3 nanoparticles weight. The weight of Al_2O_3 for different volume fractions were calculated from equation 2 and illustrated in table 1.

Figure 1: Al_2O_3 nanoparticles and surfactant.

Usually, at ambient temperature the water pH value will be around 7 and it can be reduced to 3 by mixing hydrochloric acid drops. This method was quite useful and employed to obtain a stable nanofluid in the present work. With the addition of hydrochloric acid, a layer of carboxyl was formed on the nanoparticle surface, and then it turned into a stable nanofluid. The preparation of the stable nanofluid in the experimental work could lead to corrosion of the test unit, as the nanofluid was of acidic nature. Surfactant was added to the pure water and continuously stirred till the particles got dissolved and later the known quantity of nanoparticles was added to form the nanofluid. The fluid was continuously stirred for 12 h to make the nanofluid stable. The stable nanofluid preparation was difficult attributing to the density fluctuations of nanoparticles in the base fluid. The nanofluid could be prepared usually by mixing the nanoparticles in the base fluid. For that, it requires the addition of nanoparticles using magnetic stirring for a set time period. At first, the nanoparticles were distributed uniformly all over the base fluid. However, over a period of time, the nanoparticles settled deep down inside the base fluid. The density variation of nanoparticles inside the fluid was obvious and presented in table 2.

Preparation of hybrid nanofluid

In preparation of the hybrid nanofluid, the mixture containing Al_2O_3 and CuO (each 50%) with volume fractions

Table 1: Weight of nanoparticles and surfactant for different volume fractions.

S. No.	ϕ (%)	Al_2O_3 weight (g)	Surfactant SDBS weight (g)
1	0.01	0.0397	0.00397
2	0.02	0.0798	0.00798
3	0.03	0.1195	0.01195
4	0.05	0.1991	0.01991
5	0.06	0.2389	0.02387

Table 2: Thermophysical properties of working fluids at 30 °C.

Nanoparticles/Base fluid	Al_2O_3	Water
Average diameter (nm)	47	-
Density (kg/m^3)	3970	995.7
Thermal conductivity (W/mK)	0.6133	670
Specific heat (J/kgK)	0.609	4179

0.01% and 0.03% were mixed with de-ionised water and sonicated it for one hour by using ultrasonic disruptor (KS 500F model). The Two different volume fractions of the hybrid nanofluid were considered in the present work.

Experimental procedure

Figure 2 shows evacuated tubes used in the experimental setup. Figure 3 shows the experimental setup employed in this work. Due to gravity, fluid flows from the 15-litre bucket placed at a height of 2 metre to the inlet of the solar tube collector tank through a 20 mm plastic tube. The SETC system consists of a storage tank that stores the fluid and directs the fluid through the inlet of evacuated tubes, and thus equally supplies the fluid to the evacuated tubes. The low dense heated water moves up to the tank and the entering water from inlet straight away flows through the four evacuated tubes for further progress. A copper pipe was connected to the outlet of the SETC. The copper pipe is completely winded with asbestos rope for perfect insulation. Thermocouple was inserted into the copper pipe through a T-joint that could give instantaneous temperature values. The fluid from the outlet of copper pipe enters a steel container which was surrounded with ice cubes in a thermocol box closed with a lid. The outlet of the steel container is connected with another pipe through a disposition bucket. Also, to transfer the fluid from the floor to the source, which is at 2 metre height, a motor was used. A small diameter pipe is connected to the outlet of the pump and other side of the pipe is connected to the source. Finally, the cold water (cooled to room temperature) was collected into another bucket. The motor was placed inside the bucket to ensure continuous fluid flow.

Figure 2: Evacuated tubes used in the experimental setup.

Figure 3: Arrangement for conducting research work on SETC.

Data analysis

The functioning of SETC was based on the factors considered [12, 13] for the collector fabrication and were as follows.

- Solar factors: Diffuse fraction, radiation intensity, angle of incidence between the collector and the sun.
- Ambient conditions: Wind speed, sky temperature, and ambient temperature.
- Operating conditions: Mass flow rate, fluid temperature at inlet, and collector orientation.
- The thermal efficiency (η) of SETC was determined; readings were noted during noon. During noon, as the sun rays were perpendicular, and the heat flux was at its peak. Owing to the temperature difference, the efficiency was fluctuating significantly. The efficiency was evaluated using the equations mentioned as follows.

Thermal performance calculation

The thermal efficiency of SETC was determined from the following equations.

$$\eta = \frac{Q_u}{A_c G} \tag{3}$$

$$\eta = \frac{\dot{m} C_p \left(T_{out} - T_{in}\right)}{A_c G} \tag{4}$$

Where, Q_u = Heat energy obtained from fluid temperatures; A_c = Area solar plate; and G = Solar plate constant.

Change in internal energy of fluid (ΔU):

$$\Delta U = \dot{m} C_p \left(T_{out} - T_{in}\right) \tag{5}$$

Where, C_p = Specific heat of nanofluid; T_o = fluid temperature at the outlet; and T_i = fluid temperature at the inlet.

Heat absorbed per second due to radiation.

$$Q_r = A \text{ x } G \text{ x } T \tag{6}$$

Where, G = Irradiation and T = Transmissibility.

Results and Discussion

Experiments were conducted to study the thermal performance of evacuated tubes with de-ionized water as working fluid initially, and then using Al_2O_3 nanofluid and hybrid nanofluid (Al_2O_3 50%-CuO 50%). The thermal efficiency at 5 LPH and 8 LPH was calculated at different times on a sunny day. The fluid temperature in the tank was a major parameter in the analysis and it was shown correlated in connection with mass flow rate and flow inside the collector due to density variation. It was known that the working fluid temperature in the tubes and in the tank represent the heating range of the system. Usually, in the entire day the fluid in all tubes was nearly homogeneous and the incremental temperature in the entire tube length was found to be 8 - 12 K using water as working fluid. Whereas the temperature around 10 K and 15 K was noted for Al_2O_3 nanofluid and nearly 13 K and 20 K for Al_2O_3 + CuO hybrid nanofluid. The average fluid temperature in the tube and the tank was found to be nearly equal. The results indicated highest collector efficiency of 84.23% and 94.78% using hybrid nanofluid with 0.01 and 0.03 volume fractions at 8 LPH flow rate. Figure 4 presents storage tank average temperature vs time for various working fluids at 5 LPH. Figure 5 presents temperature difference vs time for water at 5 and 8 LPH. Figure 6 presents temperature difference vs time for Al_2O_3 nanofluid at 5 and 8 LPH. Figure 7 presents temperature difference vs time for hybrid nanofluid at 5 and 8 LPH. Figure 8 presents temperature difference vs time for various working fluids at 5 LPH. Figure 9 presents temperature difference vs time for various working fluids at 8 LPH.

Conclusion

In this work, the thermal collector performance using nanofluids was examined and the influence of mass flow rate on SETC performance was noted. The testing arrangement containing inclined evacuated tubes and horizontal tank connected directly and the location of copper coil inside the tank can be utilized as heat exchanger effectively. This type of SETC can be operated as a passive system and fluid movement inside the tube collector will be achieved as per the thermosyphon principle. From the results, it was concluded that the use of hybrid nanofluid as working fluid yields higher efficiency. The energy efficiency also increases with higher volume fraction and also with higher solar radiation intensity.

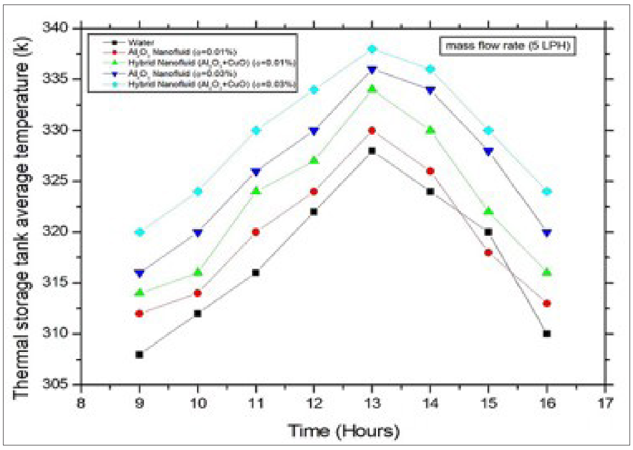

Figure 4: Storage tank average temperature vs time for various working fluids at 5 LPH.

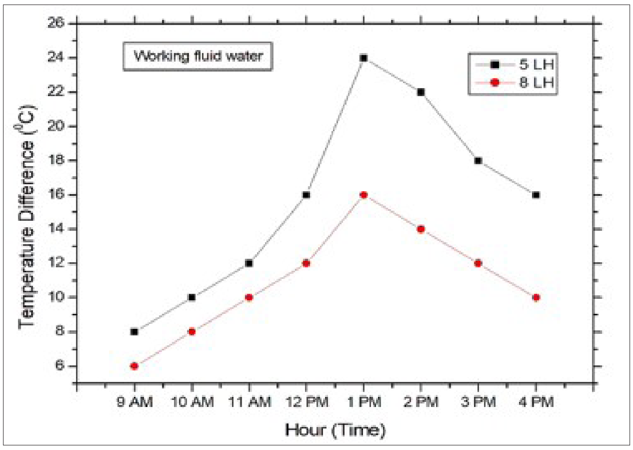

Figure 5: Temperature difference vs time for water at 5 and 8 LPH.

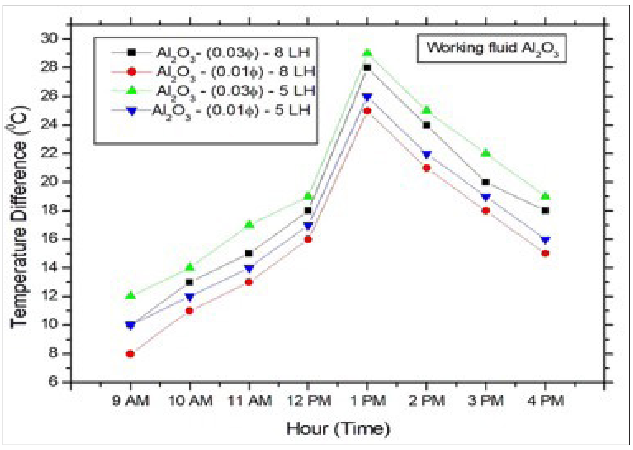

Figure 6: Temperature difference vs time for Al_2O_3 nanofluid at 5 and 8 LPH.

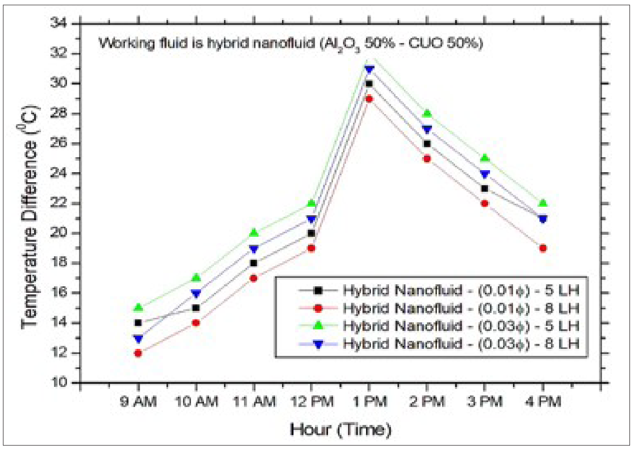

Figure 7: Temperature difference vs time for hybrid nanofluid at 5 and 8 LPH.

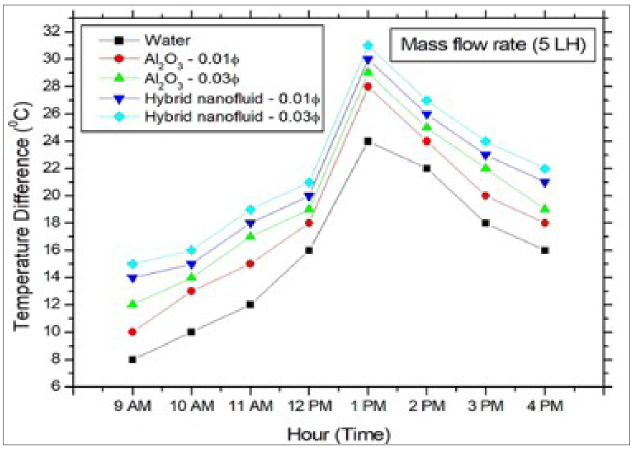

Figure 8: Temperature difference vs time for various working fluids at 5 LPH.

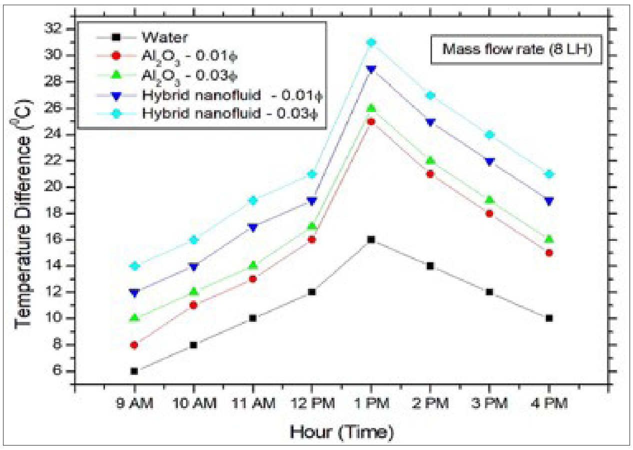

Figure 9: Temperature difference vs time for various working fluids at 8 LPH.

Acknowledgements

None.

Conflict of Interest

None.

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