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Heat Transfer Augmentation of Solar Collector Using ZnO-water Nanofluid

Deepak Kolar[1*], Vishnu Vardhan Mukkoti[1], Abhishek Chigullapally[1] and Deep Sanghani[2]

[1]*Department of Mechanical Engineering, Vardhaman College of Engineering, Hyderabad, Telangana, India*
[2]*Department of Mechanical Engineering, R.K. University, Rajkot, Gujarat, India*

[*]Correspondence to:
Deepak Kolar
Department of Mechanical Engineering,
Vardhaman College of Engineering,
Hyderabad, Telangana, India.
E-mail: deepak045@gmail.com

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Abstract

Thermal Performance of heat absorption system plays a significant role for the effective utilization of thermal energy form the sun. In this article, a water heating system with sun tracking concentrated solar collector was studied experimentally using zinc oxide (ZnO)-water nanofluid. The prime objective was to examine the ZnO nanofluid influence on the collectors' thermal performance. For this, a parabolic type solar collector (PTSC) was fabricated and experiments were conducted in summer. The PTSC performance was measured initially by using water and then compared with ZnO nanofluid with 0.2 and 0.4 volume fractions. The solar radiation intensity at test location, working fluid temperature, ambient condition, and the discharge at the heating system were measured. The results showed the overall collector efficiency enhancement by 29% and 40%, respectively.

Keywords

Solar heating system, Solar collector, ZnO-water nanofluid, Efficiency enhancement

Introduction

Thermal energy forms the sun is one of the renewable energy sources widely preferred because it is non-polluting, sustainable, and freely available. It is the potential alternative energy source to fulfil the growing energy demand. The thermal energy transmitted from sun to earth in an hour is known to be more than the total energy consumption by human beings on the earth in one year [1]. In a solar thermal heating system, the sunlight directly strikes the absorber surface and heats it up. The working fluid or water to be heated absorbs the heat while flowing through the absorber. In a system with a separate loop for working fluid comprises a heat exchanger for transferring heat from working fluid to the water to be heated. The hot water will be collected in a storage water tank until it is taken for use. If more heating is needed, it may be further provided by the use of fossil fuel or electrical heating. Solar thermal heating devices are basically categorized as passive and active devices. In the passive devices, the thermal energy absorbed is stored in the building wall itself. Contrarily, the active systems employ a solar collector to transfer the heat energy and pass it to the storage water tank [2].

The solar thermal collectors absorb the sunlight, convert into heat, and then warm up the working fluid. Solar thermal collectors exist in two types: stationary collectors and tracking concentrated collectors. The tracking concentrated collectors track the sun and concentrate the sunlight at the focal point [3]. The International Energy Agency reported the concentrated solar thermal energy demand of 1000 GW by the year 2050 [4]. Among the concentrated solar collectors, the PTSC is proven to be the most economic and large-scale technology [5]. The

PTSC consists of a parabolic reflector. The light waves from the entire parabolic surface of the trough reflect on the point of focus while the incoming solar energy rays remain parallel. The copper tube placed along the focal line of parabolic collector absorbs thermal energy and passes it to the working fluid flowing through it. The geometrical parameters of parabolic collector such as focal length, aperture area, absorber radius, angle of rim, ratio of concentration, and other parameters of optical relevance are being studied continuously to enhance the collector performance [6-8]. The fluid used in the collector is generally a combination of thermal oil or water plus some additives such as nanoparticles to enhance heat conduction. Numerous attempts have been made to augment the working fluid thermal conductivity ever since the advent of the solar thermal energy utilization.

The thermal performance of the working fluid used in the concentrated collectors investigated by using nanofluid indicated improved performance [9]. In comparison with only base fluid, the nanofluid exhibits higher fluid density, higher thermal conductivity, lower specific heat, and higher viscosity. The higher viscosity of nanofluid is in fact a drawback as it generates friction leading to a pressure drop in the flow direction that subsequently increases the pump work. The nanoparticles employed for the thermal performance enhancement of PTSC have varied diameters in the range of 4 - 100 nm. It has attracted the many researchers' attention to investigate the performance of concentrating collectors by using nanofluids (metal oxide-based nanoparticles blended in base fluid) [10, 11]. Extensive reviews have been presented to explore the influence of nanoparticles on thermal performance of solar energy collectors [12, 13]. The introduction of aluminum oxide nanoparticles in the working fluid enhanced the solar energy absorption by 10% [14]. A study conducted on solar dish type collector by using graphite nanoparticles indicated thermal performance improvement by 10% [15]. The thermal performance investigation of absorption type solar collector using silver, graphite and carbon nanotubes revealed the efficiency improvement by 5% [16]. The use of aluminum oxide nanoparticle in solar flat plate was found to enhance the collector efficiency by 28% [17]. The heat transmission capability of titanium oxide nanofluid for PTSC was investigated. The experiment conducted with different mass flow rates showed 9.5% higher energy absorption compared to water [18].

Among the metal oxide nanoparticles, the information on use of ZnO nanofluid in PTSC was found to be sparse. Therefore, in this work the ZnO nanofluid was considered to be used as working fluid. The novelty of present work was the design of PTSC that was fabricated to facilitate the thermal performance investigation using with 0.2% and 0.4% ZnO concentration experimentally. The Temperature variation and the heat transfer characteristics were determined.

Methodology

Geometry of PTSC

PTSC employs linear imaging concentration. It consists of a concentrator of parabolic cross-section, and a tubular receiver was located along the focus line of the parabolic trough. The reflector was made to focus the incident sun rays on the tubular receiver. The working fluid was made to flow through the receiver to absorb thermal energy and heat the liquid meant for heating. The radiation entering parallel to the optical plane was made to reflect such that it was focused along the tube length. The three parameters that were commonly considered to characterize the parabolic trough collector were, focal length, collector length and aperture width. The focal length was measured from the vertex of the parabola to focus point of the reflected sun rays.

Fabrication of the PTSC

The components considered for fabrication of the thermal collector were galvanized sheet metal, stainless steel and mirror finished acrylic sheet. Acrylic mirror sheet was preferred for its ease of handling, high reflectivity and cost effective. To produce the reflection surface, at first the supportive structure was fabricated first using mild steel bar of 25 mm width and 4 mm thickness. Work piece was obtained by cutting operation and then moulded into the parabolic shape. Holes were drilled on the edges of the frame to fix the reflective surface on the support structure. Reflective sheets are affixed on the parabolic trough that reflects the solar radiation through the focal point of parabolic trough. A 12.5 mm diameter copper tube was used to absorb the heat reflected by the parabolic trough and from the direct incident radiations of the sun. The copper tube was selected due to its high thermal conductivity. For the location of the copper tube accurately at the focal point, an arrangement was made by using bolts, nuts, and the L-shaped strip (Figure 1).

Measurement procedure

The copper tube (absorber) was connected to the source tank and the collecting tank with flexible tubing (Table 1). The source tank was mounted at a higher level to enable forced convection. The sunlight was concentrated on the copper tube by manual tracking the sun movement in the sky. At first, the experiment was conducted by using deionized water as working fluid and then later by using ZnO nanofluid. The fluid flow was controlled with the help of a ball valve mounted at the copper tube inlet and the discharge was measured by using a graduated flask and stopwatch. The working fluid temperature and the copper tube surface temperature were noted by using digital temperature indicator at every 30 min. The experiment was conducted for 5 h during daytime from 10:00 AM to

Figure 1: Fabricated PTSC.

3:00 PM using base fluid (water) with different ZnO concentration. The properties and the performance parameters of nanofluid were calculated. ZnO Volume Fraction (v_{ZnO}) was calculated by:

$$v_{ZnO} = \frac{\frac{W_{ZnO}}{\rho_{ZnO}}}{\frac{W_{ZnO}}{\rho_{ZnO}} + \frac{W_{bf}}{\rho_{bf}}} \quad (1)$$

Where, *W* is weight, (N); ρ is density, (kg/m^3); ZnO is zinc oxide; and *bf* is base fluid.

Nanofluid density (ρ_{nf}) was calculated by:

$$\rho_{nf} = (1 - v_{ZnO})\rho_{bf} + v_{ZnO}\rho_{ZnO} \quad (2)$$

Nanofluid specific heat ($c_{p_{nf}}$) was calculated by:

$$C_{p_{nf}} = \frac{(1 - v_{ZnO})(\rho c_p)_{bf} + (v_{ZnO})(\rho c_p)_{ZnO}}{\rho_{nf}} \quad (3)$$

Where, *nf* is nanofluid.

Heat gain (Q_g) was calculated by:

$$Q_g = mc_p(T_o - T_i) \quad (4)$$

Where, *m* is fluid flow rate (kg/s); c_p is specific heat of the working fluid (kJ/kgK); and T_e and T_i is exit and inlet temperature of the fluid (°C).

The collector efficiency (η_c) was calculated by [18]:

$$\eta_c = \frac{Q_g}{A_a.I} = \frac{mc_p(T_o - T_i)}{A_a.I} \quad (5)$$

Where, *Aa* is Collector aperture area (m^2) and *I* is Normal direct irradiance (W/m^2).

Results and Discussion

Figure 2 depicts the outlet temperature variation over the test duration. The tests were carried out by making use of deionized water and ZnO nanofluid with concentrations ranging from 0.2 to 0.4. The fluid flow rate was fixed at 132 L/h. The working fluid temperature increased due to increase in solar intensity with time during the test span (Table 2). It was noticed that the temperature of nanofluid at the outlet of PTSC was higher than water. Also the temperature seen to be increased with higher concentration of ZnO in the working fluid. The highest temperature was observed to be 50 °C using 0.4% ZnO nanofluid. The heat flux variation with time is depicted in figure 3. The heat flux increases with time as result of increased working fluid temperature difference. Compared with water, ZnO nanofluids results higher heat flux. The peak heat flux noticed was 1560.07 W/m^2 using 0.4% ZnO nanofluid. The heat flux increased with higher concentration of ZnO in the base fluid. Figure 4 depicts the collector efficiency variation during the test period. The variation of efficiencies was due to variation in the heat flux and the solar intensity.

Table 1: Specifications of PTSC.

Trough length, m	1
Absorber tube diameter, mm	12.5
Parabola angle, deg.	120
Aperture width, m	0.7
Focal length, m	0.3

Table 2: Variation of temperature difference with time.

Time interval	Temperature difference (°C)		
	Water	ZnO (0.2%)	ZnO (0.2%)
10:00 - 10:30	5.0	7.0	8.5
10:30 - 11:00	5.0	7.3	8.8
11:00 - 11:30	5.1	7.6	9.1
11:30 - 12:00	5.3	7.7	9.2
12:00 - 12:30	5.4	8.0	9.2
12:30 - 13:00	5.6	8.1	9.5
13:00 - 13:30	5.8	8.3	9.7
13:30 - 14:00	6.0	8.5	9.8
14:00 - 14:30	6.5	9.0	10.5
14:30 - 15:00	7.0	9.5	11.0

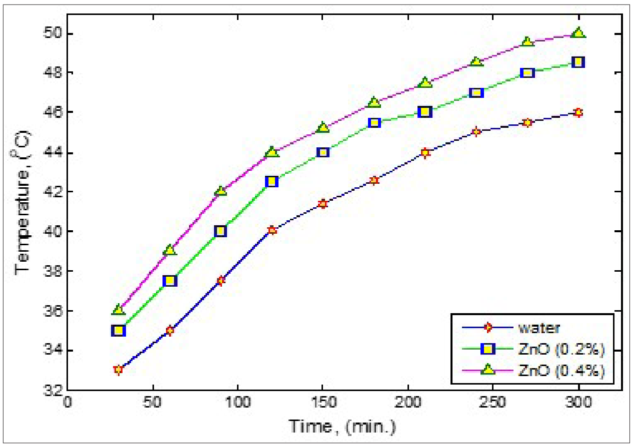

Figure 2: Variation of outlet temperature of working fluid with time.

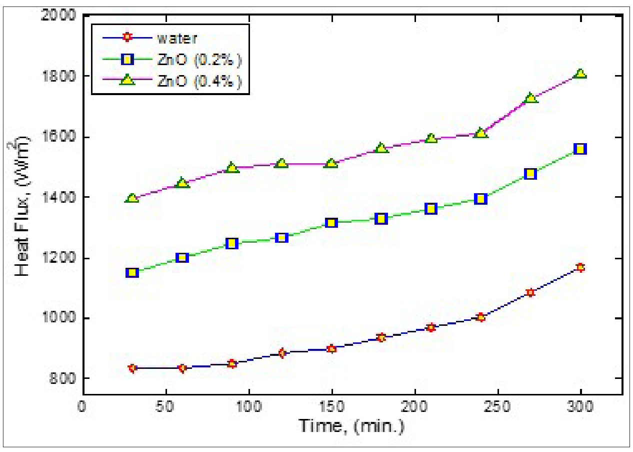

Figure 3: Variation of heat flux with time.

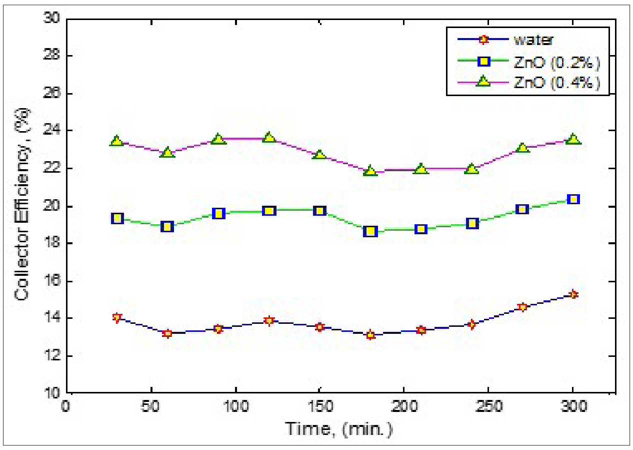

Figure 4: Variation of collector efficiency with time.

The working fluid with 0.4% ZnO nanofluid shows the highest collector efficiency. With that, an average value of 22.82% was obtained, which was 40% greater than that of pure water.

Conclusion

Based on the experimental results, it was concluded that the heat transfer capability of ZnO nanofluid could be utilized for PTSC applications. ZnO nanofluid usage increases the thermal performance of PTSC. The heat flux enhancement was achieved owing to the improvement in thermal conductivity and specific heat of the working fluid. The performance of PTSC can be enhanced by 40% by using the ZnO-water nanofluid with a volume fraction of 0.4.

Acknowledgements

None.

Conflict of Interest

None.

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