3. Solar parabolic trough collector using nano fluids

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ABSTRACT:

The efficiency of a parabolic trough solar collector (PTSC) was enhanced by using TiO_2/DI-H_2O nanofluid. Test samples consisting of nanofluids with concentrations of 0.05%, 0.1%, 0.2%, and 0.5% were compared with deionized water (the base fluid) at different flow rates under turbulent flow regime ($2950 \leq Re \leq 8142$). All the experiments were conducted to meet ASHRAE 93(2010) standards. Heat transfer and flow characteristics of nanofluids through the collector were studied, and empirical correlations were developed in terms of Nusselt number, friction factor, and performance index. The convective heat transfer coefficient was improved up to 22.76% by using TiO_2 nanofluids instead of the base fluid. It was found that TiO_2 nanofluid with a volume concentration of 0.2% (at a mass flow rate of 0.0667 kg/s) can provide the maximum efficiency enhancement in the PTSC (8.66% higher than the water-based collector). Consequently, the absorbed energy parameter was found to be 9.5% greater than that of the base fluid.

Hence, the present work focuses on PTSC thermal performance and heat transfer characteristics with a transient heat flux method using TiO_2 nanofluids. Another key goal of this investigation is to determine the maximum possible amount of heat energy from a stationary concentrating collector using low-volume concentration of TiO_2 nanofluid, as well as to estimate the efficiency and heat transfer characteristics of the PTSC. Based on the experimental outcomes, empirical correlations for the Nusselt number, friction factor, and performance index are developed using multiple linear regression models.

1. Experimental methods and instrumentation

The design parameters for a solar PTC are the aperture, rim angle, acceptance angle, focus, depth, arc length, and receiver tube diameter, which were determined using equations proposed by Kalogirou [38]. The mathematical model was simulated using the TracePro software package for reflectivity, absorptivity, and transmissivity above 0.9. The solar PTC design was mathematically verified by Duffie[39]. The experimental setup was located in Chennai, India (latitude 13^o 02' 33" N and longitude 80^o 06' 03" E) as shown in Fig.1–2.

The collector was made of an anodized aluminum reflector sheet with a mean measured reflectance value of 0.94. The receiver tube was a 2m copper tube with inner/outer diameters of 13 and 16 mm, respectively. The receiver tube was surrounded by a transparent borosilicate glass tube with a 30mm internal diameter and 34mm external diameter. The arrangement was sealed by a high temperature resistant cork in order to maintain a partial vacuum to reduce convective heat losses and harness the incident solar energy by the greenhouse effect.

Carbon black powder up to 1 µm in thickness is coated over the external surface area of the absorber tube. The outer surface temperature was measured with WIKA TC50, and the thermo couples were placed at lengths of 20, 50, 90, 120, and 160 cm apart. The gradient pressure across the test rig was measured using an M5100 piezoelectric pressure transducer with an accuracy of ±1% and a range of 0-3.5bar. The TiO_2nanofluid was stored in a reservoir and circulated to the entrance of the absorber tube by a centrifugal pump, which was operated by a rotameter with a range of 0–10lpm and accuracy of ±1%. The absorber tube outlet was connected to a heat exchanger to diminish the temperature of the nanofluids. While the heat exchanger reduced the temperature by up to 3°C, a constant temperature bath was employed to balance the nanofluid temperature in accordance with the specifications of the ASHRAE 93(2010) [40] standards. The trough collector was always situated perpendicular to the solar noon, and the thermal performance of the non-tracking method (stationary) was studied according to the ASHRAE standards. The test parameters were also recorded based on these standards, including the ambient temperature, flow rate, wind velocity, solar radiation, temperatures at the entry and outlet of the test section, and gradient pressure. The pyranometer (SP Lite2 silicon) was used to determine the direct solar radiation, while the wind velocity and ambient temperatures were measured using a vane-type anemometer with a range of 0–25 m/s and accuracy of ±3%. The solar collector test facility was designed and mounted for outside ambient conditions with a mean wind speed of 5 m/s with an operating humidity range of 60–80%. The support structure was designed to resist a maximum wind speed of about 40 m/s.

Fig.1. Photograph of the parabolic trough solar collector

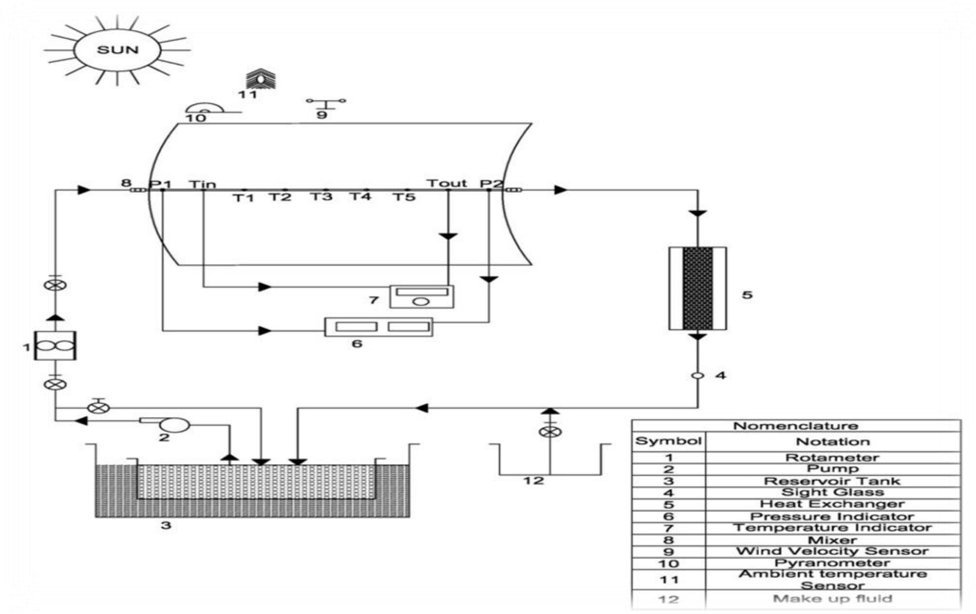

Fig.2. Graphical layout of the experimental setup

2. Conclusions

This study investigated the performance of the TiO_2nanofluid to document its heat transfer capability for solar PTC applications. Tests were conducted using different nanoparticle concentrations and mass flow rates, and the following outcomes were obtained:

1. Nanofluids have a 9.5% higher absorbed energy factor $F_R(\tau\alpha)$ compared to water.
2. At ϕ=0.2% and a mass flow rate of 0.0667 kg/s, the absorbed energy factor $F_R(\tau\alpha)$has a higher value, while the removal energy factor $F_R(U_L)$ value fluctuates marginally.
3. A higher convective heat transfer coefficient is achieved at a maximum flow rate of 0.0667kg/s because of the lower temperature gradient (ΔT=3.89°C). The overall collector heat loss coefficient (U_L) does not deviate significantly from 8.86 W/m^2K despite variations in flow rates and concentrations.
4. Correlations show that the Nusselt number, friction factor, and performance index are in the Reynolds number range of ($2950 \leq Re \leq 8142$).

5. The performance index has a peak value of 1.39 for the nanofluid with a volume concentration of 0.2% and a mass flow rate of 0.0667 kg/s.
6. The maximum overall efficiency of the PTSC using TiO_2 nanofluid is 57%, which is 9% greater than that of the base fluid.
7. The empirical correlations for the heat transfer characteristics are as follows:

$$\mathrm{Nu_c} = 0.02169\, Re^{0.836} Pr^{0.071} (1 + \phi)^{0.30}$$

$$f_c = 0.46673\, Re^{-0.349} Pr^{0.246} (1 + \phi)^{0.204}$$

$$P_{indexc} = 0.69628\, Re^{0.0399} (1 + \phi)^{1.387}$$

CENTRE FOR EXCELLENCE IN ENERGY AND NANO TECHNOLOGY

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PROJECT MEMBERS DETAIL:

S.No	Name of The Project	Lab Utilization	Student Participated in the Project
1	Improving Thermal Performance Of Solar PTC Using Nano fluids With ASHRAE Standards	Sonication, PTC test rig, solar power meter, temperature sensors, anemometer, calibrated flask,	**(ACY 2016-17)** Sibi S P Sandeep C M S L Vigneshwar
2	Heat Transfer Augmentation Of Solar PTC Using Nano Fluids		**(ACY 2016-17)** SashankRao A Surya M G S Yuvaraj Rishal Raj Kumar

PROJECT OUTCOME:

Paper Published

1. Subramani, J., Nagarajan, P.K., Wongwises, S., El-Agouz, S.A. and Sathyamurthy, R., Experimental study on the thermal performance and heat transfer characteristics of solar parabolic trough collector using Al2O3 nanofluids. *Environmental Progress & Sustainable Energy*.
2. Subramani, J., P. K. Nagarajan, OmidMahian, and Ravishankar Sathyamurthy. "Efficiency and heat transfer improvements in a parabolic trough solar collector using TiO 2 nanofluids under turbulent flow regime." *Renewable Energy*(2017).