engineering proceedings

Proceeding Paper

Design and Experimental Investigation of Thermosiphoning Heat Transfer through Nanofluids in Compound Parabolic Collector †

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† Presented at the International Conference on Energy, Power and Environment, University of Gujrat, Pakistan, 11–12 November 2021.

Abstract: The finite nature of fossil fuels and their adverse effects on the environment have forced mankind to look for alternate energy sources. Solar energy is one of them, and Pakistan has immense potential. This paper specifically focuses on achieving these purposes by using compound parabolic collectors. They are non-tracking and are used for low to medium temperature ranges. To achieve thermosiphoning, nanofluids, which have a high heat transfer rate, are used. Flow rates and outlet temperatures are obtained, by experimentation and by a numerical analysis with water and nanofluids (Fe_2O_3 and Al_2O_3). The maximum numerical flow rate achieved was 9.3 mL/s with Fe_2O_3. The maximum flow rate achieved in the outdoor setup was 10.78 mL/s. Numerical and experimental results were validated with previous research with some deviation. The use of nanofluids and thermosiphoning can greatly enhance the performance of our system and reduce the mechanical work of a pump in a hybrid system.

Keywords: nanofluids; compound parabolic collectors (CPCs); thermosiphoning; buoyant pressure; absorber; thermal conductivity; boundary conditions

Citation: Ahmad, S.; Ali, M.; Ali, F.; Ahmad, S.; Ahmad, D.; Iftikhar, O. Design and Experimental Investigation of Thermosiphoning Heat Transfer through Nanofluids in Compound Parabolic Collector. *Eng. Proc.* **2021**, *12*, 39. https://doi.org/10.3390/engproc2021012039

Academic Editor: Shahid Iqbal

Published: 17 January 2022

1. Introduction

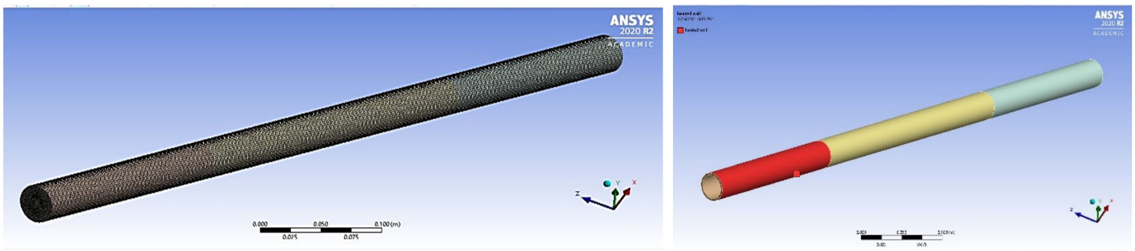
Compound parabolic collectors are composed of a trough with two sections of parabolas facing each other, such that any radiation within the acceptance angle finds its way to the absorber [1]. The heat gained is then transferred to a working fluid. Recently, in research, it was established that adding nanoparticles to the working fluid can enhance the thermal conductivity and, hence, the system efficiency. Thermosiphoning is a method of a passive heat exchange that depends on natural convection and allows a fluid to circulate without the need of a pump. The aim is to design and experimentally investigate the thermosiphoning heat transfer through nanofluids in CPCs. Objectives that have been accomplished are the design of a receiver tube on ANSYS and simulated thermosiphoning with nanofluids, the design and fabrication of indoor and outdoor setups, development of a mathematical model, preparation of metallic nanofluids, testing of thermosiphoning using nanofluids determination of an intermittent flow rate and outlet temperatures and, finally, the validation of numerical results.

The main driving force is the buoyant pressure of the fluid overcoming the pipe frictional losses [2]. Numerous attempts have been undertaken to improve the thermal conductivity of a working fluid using nanoparticles. Khullar et al. [3] examined nanofluids, their applications and usage in concentrating a parabolic trough solar collector (CPT). Emmanouil et al. [4] used the thermosiphoning phenomenon as a closed loop using a heat exchanger as a condenser. For understanding the thermosiphoning phenomenon in the solar system, Welander [5] considered the theoretical simulated model using different base fluids, considering that the pressure differential and a buoyancy force move the fluid and are retarded by a frictional force. Lu et al. [6] concluded that the best possible concentration was 1.20% and the increase in the thermal conductivity was around 30%. Otanicar et al. [7] performed experiments to study the effect of using different nanofluids as a working fluid in different solar collectors. Naphon et al. [8] analyzed the heat transfer efficiency of the thermosiphoning setup. Verma et al. [9] experimentally investigated the effect of a mass flow rate and mass fraction by considering the Al_2O_3 nanofluid as the working fluid. There are studies using thermosiphoning in a flat plat or parabolic collectors to some extent, but there is a considerable research gap in the use of thermosiphoning with compound parabolic collectors.

2. Methodology

2.1. Numerical Analysis

ANSYS 2021 R1 was used to simulate the receiver tube in the thermosiphon system model. Fluent module with pressure-based solver was used for solving this buoyancy-driven case. Steps taken to develop the receiver tube model were creating geometry, edge sizing, tube sectioning and meshing as shown in Figure 1.



(a) (b)

Figure 1. (**a**) Receiver tube meshing. (**b**) Tube sectioning.

Aspect ratio and skewness were observed as main mesh quality parameters. Grid independence was also observed. Methods that we used for running simulations were Presto Model, Boussinesq Model and SIMPLE Model. Some boundary conditions were imposed such as inlet velocity was set at 0 m/s, inlet temperature at 300 K, pipe wall temperature at 420 K and, finally, the outlet pressure (gauge) at 0 Pa. Then, simulations were performed using different working fluids, water, water + Al_2O_3 and water + Fe_2O_3.

2.2. Experimentation

Experimentation included performance of thermosiphoning on indoor setup by using nanofluid (Fe_2O_3 + H_2O). An artificial heating source was used to perform thermosiphoning on an indoor setup. The indoor setup included a heating coil, K-type thermo couple, beaker and copper tubes of different sizes. Effect of different parameters such as the angle of plate, nature of fluid and type of inlet were studied. K-type thermocouple was used to measure the temperature at inlet and outlet of system. Indoor setup is shown in Figure 2.

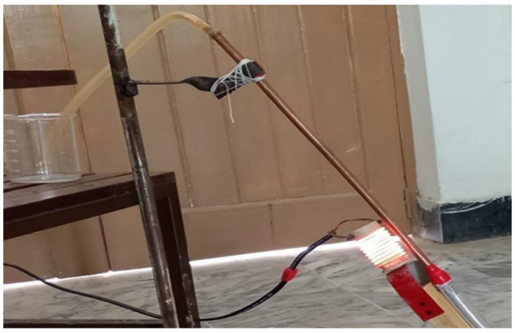
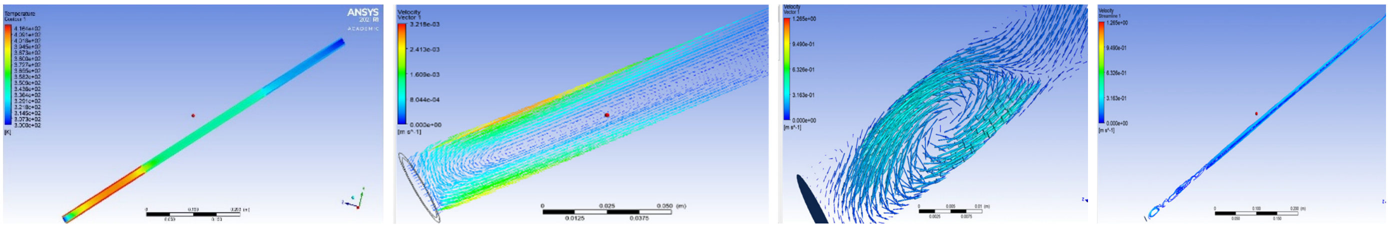


Figure 2. Indoor setup.

3. Results and Discussion

Numerical results were obtained using the ANSYS transient simulations. The results revealed that the outlet temperature varied greatly from 330 K for water to 359 K for the iron oxide nanofluid due to a temperature enhancement. The temperature contours are shown in Figure 3. As thermosiphoning started, there was a chaotic swirling phenomenon near the heated section and a reverse flow produced a vortex region as shown by the velocity streamlines and vectors, and then there was a smooth flow in the other regions of the tube. The maximum outlet velocity was achieved with the iron oxide nanofluid (0.0734 m/s) as compared to water (0.02776 m/s). The flow rates obtained numerically in the case of water, Al_2O_3 and the Fe_2O_3 nanofluid were 3.5, 4.5 and 9.3 mL/s, respectively.



(**a**) (**b**) (**c**) (**d**)

Figure 3. (**a**) Temperature contours. (**b**) Velocity vectors. (**c**) Velocity vectors at heated section. (**d**) Velocity streamlines.

The results show that with the increase in temperature, an increase in the outlet velocity and flow rate was achieved. Numerical results are shown in Figure 3.

In the case of the indoor experimentation, the main parameters of interest were the outlet temperature, volume accumulated and intermittent flow rate. There were eight different cases for water and four for the nanofluid (water + Fe_2O_3). The angle for these cases was 45°. A similar set of cases was also taken at 30. Except in case 1, all cases used a $\frac{1}{2}$ inch diameter tube. The receiver length for case 1-N and 3-N was 2.5 ft, while for 2-N and 4-N the receiver length was 1.5 ft. The nanofluid concentration for 1-N and 2-N was 0.025%, and 0.050% for 3-N and 4-N. The results revealed that thermosiphoning started early in the nanofluid. The accumulated volume increased with time, and the increase was rapid in the case of nanofluids, and a higher flow rate was achieved with a smaller diameter and length of tube. The highest flow rate of 7.3 mL/s was achieved in case 4-N, which had a higher concentration of nanoparticles, while for water, case 4 had a flow rate of 4.32 mL/s. A higher suction head in case 3 caused a continuous flow rate of 55 mL/s until the temperature of water dropped down a critical amount. The temperature increased with time and, in general, thermosiphoning started at about 86 °C with a temperature difference of about 35 °C between the outlet and inlet, and there was a rapid change in temperature due to the reduction in fluid volume. There was an increase in the flow rate and outlet velocity when a shorter diameter and length tube was employed. For a larger system size, the incident heating should be increased. Thermosiphoning trends are shown in Figure 4.

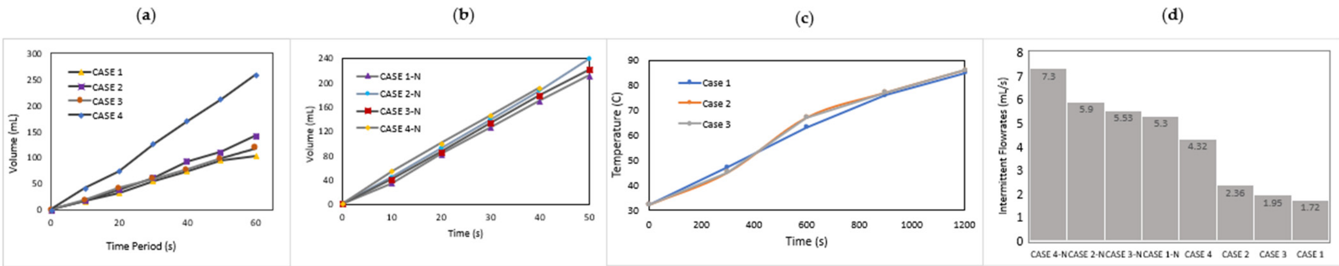


Figure 4. (**a**) Thermosiphoning with water; (**b**) Thermosiphoning with nanofluid; (**c**) Variation of temperature; (**d**) Intermittent flow rates.

The literature available on thermosiphoning using a compound parabolic collector is scarce, but the comparison of numerical results with other literature revealed a good relevance between the trends and velocity streamline behavior. The use of nanofluids greatly enhanced the system performance by enhancing the thermal properties, and the thermosiphon could be employed in a hybrid manner. In future, a further study should be conducted to develop a closed-loop thermosiphon and experimented with in outdoor conditions.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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