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Research Article

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Experimental Analysis of Closed Loop Pulsating Heat Pipe Working with Water Based Nanofluid at Different Concentrations

Santhisree Nerella*, **Bhramara Panitapu, Sudheer Nakka, Maruthi Rao Chella and Kalyan Charan Agir**

Department of Mechanical Engineering, Matrusri Engineering College, Hyderabad, Telangana, India

***Correspondence to:**
Santhisree Nerella
Department of Mechanical Engineering,
Matrusri Engineering College,
Hyderabad, Telangana, India.
E-mail: nerellasanthi@gmail.com

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Abstract

The experimental investigation focused on the performance of a multi-turn closed loop pulsating heat pipe (CLPHP) with inner and outer diameters of 2 mm and 3.1 mm, respectively. This investigation was conducted under various conditions, including different fill ratios of 50% and 60%, with heat input applied at the bottom in a vertical orientation. The study employed two different working fluids: water and a water-based nanofluid containing SiO_2 at varying concentrations (0.1%, 0.5%, and 1%). The addition of SiO_2 nanoparticles was intended to enhance the performance of the CLPHP due to their superior thermal conductivity properties. The analysis, focusing on thermal resistance as a performance metric, confirmed that a 50% fill ratio is optimal for the CLPHP's performance. However, at a 60% fill ratio, superior performance was observed when lower heat inputs were applied. The experimental results demonstrated that the lowest overall thermal resistance was achieved when a 1% concentration of nanofluid was added to the base fluid. This result was found to be even better than the thermal resistance achieved with pure water.

Keywords

Closed loop pulsating heat pipe, Fill ratio, Nanofluids, Thermal resistance, Working fluid

Introduction

A CLPHP falls into a unique class of heat pipes, distinguishing itself by lacking a wick. It operates passively, facilitating two-phase heat transfer through its components, including an evaporator, condenser, and adiabatic sections. Akachi first invented pulsating heat pipe (PHP) [1]. Heat transfer enhancement is due to the self-sustainment of fluid motion oscillation. The PHPs have been considered for major cooling applications because of their light weight (No wick), simple in design, less weight and also can operate at higher heat values. Cooling of electronic devices, space devices and heat exchangers are major areas where CLPHP plays a major role. Lot of research is going on theoretical and experimental studies of PHP [2, 3]. These studies show that the performance of CLPHP is vigorously influenced by many variables which include physical, geometrical, and operational parameters [4]. The intricacies in the fluid distribution in CLPHP results fluid fluctuations and hence the temperature differences in evaporator to condenser flow. The studies related to fluid flow visualization show that the experiments have been carried out by incorporating glass tubes in the adiabatic section [5].

Due to rapid rise of heat dissipation values of electronic devices, performance improvement in CLPHP's has become vital nowadays. Performance parameters such as heat input, internal diameter, volumetric fill ratio, orientation, number of tubes, and working fluid play a vital role to improve heat transfer characteristics of CLPHP. Among all parameters the important characteristic is working fluid selection. In the state-of-the-art nanofluids are viewed as the advanced fluids as they have higher thermal conductivity values [6]. The working fluid is formed by the suspension of nanoparticles in the base fluid. As the surface area increases, the performance of the base fluid improves. When choosing a working fluid for two-phase heat transfer, it's important to take into account not only the thermal conductivity and viscosity of the nanofluid but also other fluid properties like specific heat, boiling point, and fluid density [7].

Nowadays CLPHP working with nanofluids is an emerging area for heat transfer enhancement and results in a notable cut in the thermal resistance value which is an output parameter. The experiments with silver nanofluid at lower concentrations show better performance and water-based diamond nanofluid shows an ultimate improvement in performance due to robust fluid flow oscillations [8]. Experimental studies show that either the improvement or lack of performance is only due to the behavior of nanoparticle dispersion the base fluids [9]. CLPHP with nanofluids is still undergoing study and an investigational research have to be needed because nanoparticles suspension in small concentrations will not be sufficient for improvement of heat transfer, there should be an additional contribution is also required with other influencing parameters [10, 11].

In this current research, an experiment was conducted involving an eight-turn CLPHP. The working fluid is formed as a colloidal solution with water and SiO_2 nanoparticles [12]. The fluid flow visualization through glass tubes helps in better understanding of performance.

Experimental setup

Copper tube bent into 8 U-turns with a length of 264 mm, and capillary dimensions of 2 mm and 3.1 mm is considered. CLPHP consists of a heating zone-evaporator, adiabatic and a cooling zone-condenser (Figure 1). Internal diameter 3.1 mm and 4.5 mm outer diameter Borosilicate glass tube of 120 mm length is placed to visualize the fluid fluctuations in adiabatic section. The dimensions are of length of 42 mm, 170 mm, and 52 mm are taken evaporator, adiabatic and condenser, respectively (Figure 2). A layer of insulating material is inserted to maintain the system without any heat loss. The tube was bent into 16 channels in serpentine manner [11].

Experimental procedure is as follows: (1) Collect the base fluid and nanofluid particles, (2) Prepare the nanofluid concentrations and prepared working fluid as per the requirements, (3) Check the power supply, (4) Enable the data logger system, (5) Regulate the voltmeter and ammeter readings to start the PHP initially, (6) Maintain the input heat till the recorded temperature achieves tenacity, (7) Record the readings of temperature at both ends of cooling jacket, and (8) Regulate the flow rate such a way to achieve the above difference.

Results and Discussion

Experiments are carried out by considering SiO_2 nanofluid in 0.1%, 0.5%, and 1% concentrations in base fluid water. Different heat inputs 20, 40, 60, 80, and 100 W are supplied to the evaporator. The temperatures are recorded at different locations of the setup. Initially an experimental run is done for base fluid and then nanofluid solution is considered.

Figure 1: Experimental Setup.

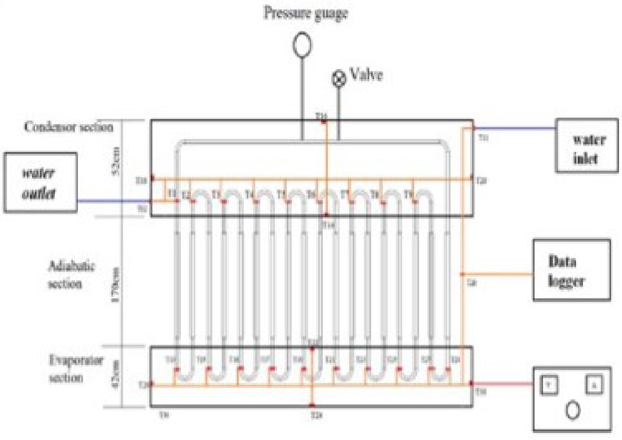

Figure 2: Schematic of CLPHP.

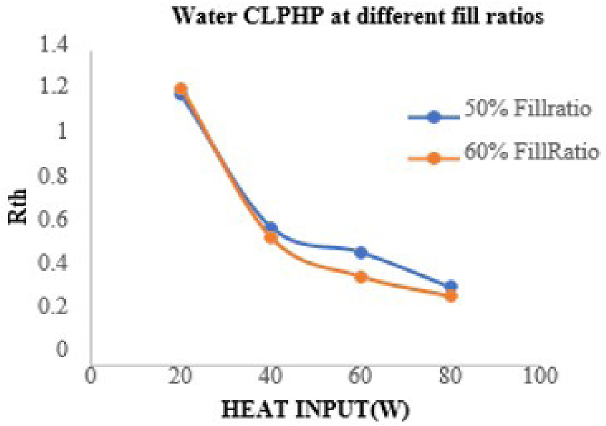

Figure 3: Thermal resistance at different fill ratios (Water).

CLPHP performance with water

After reaching the desired water level, the experimental trial commenced. Heat was applied at 20, 40, 60, and 80 W, and temperatures were recorded over a 5-second period. When compared to a 50% fill ratio, it was observed that water exhibited the lowest thermal resistance, as depicted in figure 3. The thermal resistance decreased as the heat input increased, reaching its highest temperature at 80 W [10].

CLPHP performance with water based 0.1% SiO_2 nanofluid

The experiment continued by dispersing 0.1 % of SiO_2 nanoparticles in base fluid. 20 W, 40 W, and 60 W heat inputs are supplied at evaporator section. Fluid is filled in the tubes in 50% and 60% fill ratios. The temperatures at located thermocouples are recorded in data logger. The results are plotted as shown in figure 4.

It is observed that fluid fluctuations are started at 80.2° at 80 W and 74.9° at 100 W for 50% fill ratio and 80.4° at 80 W, 74.4° at 100 W for 60% fill ratio and maximum temperature attained by the nanofluid (SiO_2 of 0.1% g/L) at 100 W is 101.6° for 60% fill ratio and maximum temperature attained by the nanofluid (SiO_2 of 0.1% g/L) at 100 W is 107.3° for 50% fill ratio.

CLPHP performance with water based 0.5% SiO_2 nanofluid

The experiment involves mixing 0.5% SiO_2 nanoparticles into a base fluid. Heat inputs of 20 W, 40 W, and 60 W are then applied to the evaporator section. The temperatures at the evaporator and condenser tubes, which are equipped with thermocouples, are logged, and recorded. Readings are recorded for 50% and 60% fill ratios. The readings plotted as shown in figure 5.

The onset of fluid pulsation occurs at 63° when the fill ratio is 50% and at 68° when the fill ratio is 60%. When using nanofluid (with 0.5% g/L SiO_2), a temperature of 103° is reached at a 50% fill ratio, while at a 60% fill ratio, it reaches 100.6 °C.

CLPHP performance with water based 1% SiO_2 nanofluid

By dispersing 1.0% of SiO_2 nanoparticles in base fluid experiments are run. The temperatures are recorded in data logger. Readings are recorded for 50% and 60% fill ratios. The findings reveal that fluid pulsation initiated at 76° when subjected to 80 W and 76.3° when exposed to 100 W, both under a 50% fill ratio. Similarly, under a 60% fill ratio, the temperatures recorded were 82.1° at 80 W and 75° at 100 W. The highest temperature reached by the nanofluid (containing 1% g/L SiO_2) under a 60% fill ratio was 101.5° at 100 W, whereas at a 50% fill ratio, it reached 101.7° at 100 W. These results are illustrated in figure 6.

Comparing working fluids (water and water-based nanofluid) at various concentrations with a 50% fill ratio

The experimental results are compared for 50% fill ratio at 60 W are shown below. When compared between nanofluid of different concentrations, the more mass concentrated one got less thermal resistance. The results are tabulated and plotted as shown in figure 7.

Among all considered fluids water shows the highest thermal resistance value. Adding nanofluid to base fluid even though in very less concentration values improves the performance. Among all the concentrations 1% concentration shows least value and better performance.

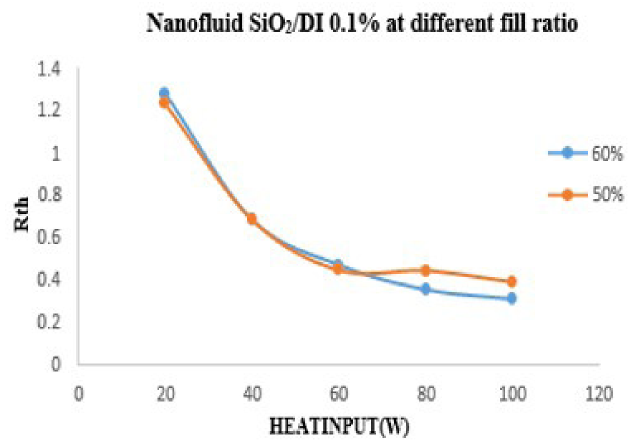

Figure 4: Thermal resistance at different fill ratios (0.1% g/L SiO_2 nanofluid).

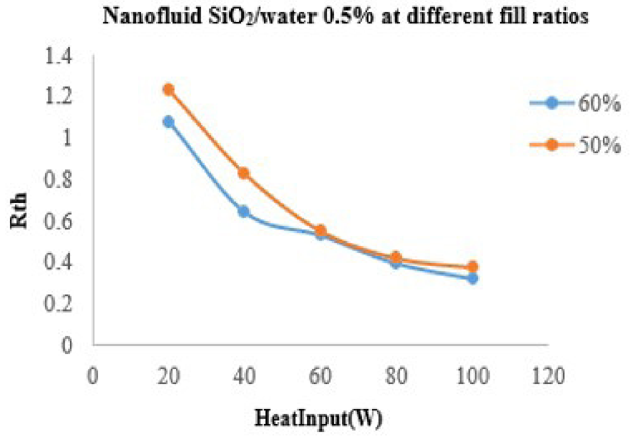

Figure 5: Thermal resistance at different fill ratios (0.5% g/L SiO_2 nanofluid).

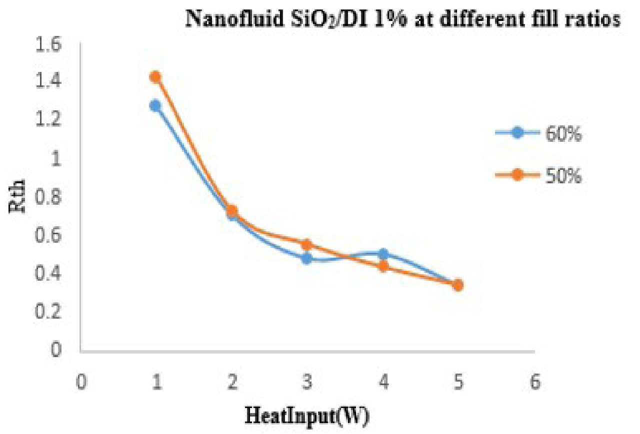

Figure 6: Thermal resistance at different fill ratios (1% g/L SiO_2 nanofluid).

Comparison of nanofluid at different concentrations in percentage with base fluid water at 50% fill ratio

With respect to water base fluid there is percentage 20% increase with 0.1% concentration nanoparticle is observed. And 24% increase is observed with 0.5% concentration whereas with 1% concentration nanoparticle there is 33% increase in performance is observed (Figure 8).

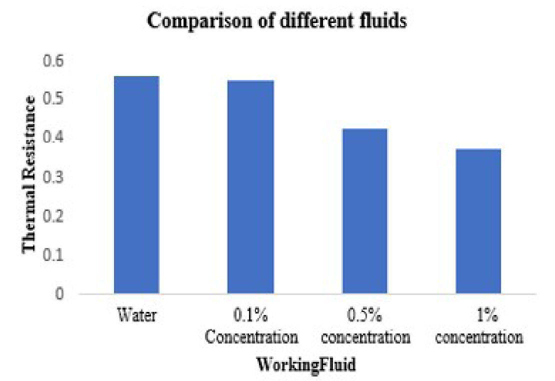

Figure 7: Variation of thermal resistance for considered working fluids (50% fill ratio), 60 W.

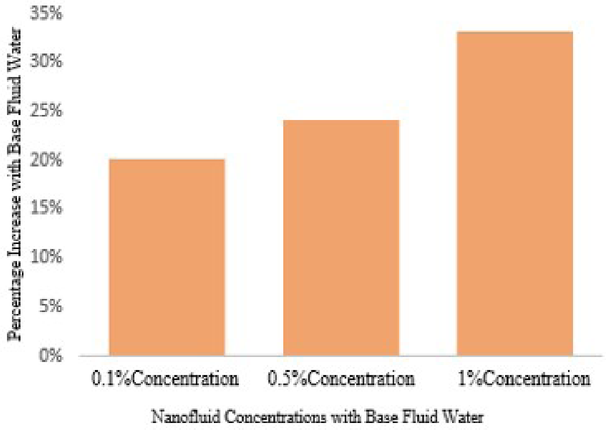

Figure 8: Performance increase in percentage of nanofluid with different concentrations at 50% fill ratio.

Conclusions

The study involved conducting experiments on a CLPHP using both pure water and a water-based nanofluid containing SiO_2 at various concentrations, specifically 0.1%, 0.5%, and 1%. CLPHP are commonly used in applications such as electronic cooling devices, space technology, refrigeration systems as condensers, and fabrication technology. From the experimental results, the following conclusions were drawn.

- For all the fluids at evaporator as the input supply of heat increased, thermal resistance decreases.
- The primary influential characteristic of a working fluid is its boiling point. Within the context of fluid flow distribution, the boiling point plays a pivotal role in shaping the disturbances in fluid flow, which manifest as both liquid and vapor bubbles.
- Initially fluid pulsating action doesn't initiate, upon supplying heat input. It takes different time gaps for different fluids. For water it is 500 sec and for other fluids such as SiO_2/DI 0.1% - 285 sec, 0.5% - 245 sec, and 1% - 225 sec.
- Thermal resistance is at its minimum when the fluid level is at 50%, with values ranging between 50% and 60%. As the fill ratio values increase, thermal resistance also increases.
- The presence of nanoparticles causes changes in the fluid interface, which in turn affects the thermal resistance of SiO_2 nanofluid.
- The heat pipe's thermal resistance diminishes as the concentration of nanoparticles increases.
- The maximum value of thermal resistance is obtained at 100 W of 60% fill ratio for 0.5% SiO_2 concentration of which is 0.3216 K/W.
- With respect to water base fluid there is percentage 20% increase with 0.1% concentration nanoparticle, 24% with 0.5% concentration and with 1% concentration nanoparticle there is 33% increase in performance is observed.

Acknowledgements

None.

Conflict of Interest

None.

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