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Performance Analysis of Closed Loop Pulsating Heat Pipe Using Nanofluid

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ABSTRACT
A Closed Loop Pulsating Heat Pipe (CLPHP) is a self-excited thermally driven two phase passive heat transfer device, which transfers heat from one location to another with a negligible temperature drop. Its operation depends on the phase change of a working fluid within the loop. This research investigates the effect of concentration of water based Aluminum oxide nanofluid (*i.e.* Al_2O_3 Water) on thermal resistance of closed Loop Pulsating Heat Pipe (CLPHP). CLPHP is made up of copper tubing with internal diameter of 3mm and outer diameter of 4mm. the tube had 2 meandering turns. The length of evaporator was 380mm and condenser section was 360mm. Experiment was conducted in vertical orientation with having 50% filling ratio (FR). Heat load varied from 6 Watt to 72 Watt. The concentration of Al2O3Water nanofluid was 0.25%, 0.5%, 0.75% and 1% w/v. The various temperatures were recorded on the outer wall of the evaporator and condenser section and inlet & outlet of cooling water. Overall thermal resistance at different heat inputs was calculated. It is found that thermal resistance of CLPHP using Al2O3water nanofluid as working fluid was better than thermal resistance when pure water is used.

Key words: Closed loop pulsating heat pipe, Al_2O_3, nanofluid, Concentration, Filling Ratio

INTRODUCTION

Due to huge development in electronic filed, thermal management of high performance chips has become a challenging issue to direct heat transfer investigations and again in industries, there had been always a great demand for having robust and promising cooling devices. For this reason, pulsating heat pipe is best option due to simplicity of structure, reliability and low manufacturing cost.

A heat pipe is simply a type of heat exchanger that is very simple in construction, easy and straight forward for use. Improvements have been done over time in heat pipes used for heat transfer. Over the years, researchers have continuously search new methods of heat transfer augmentation. The result of employing different working fluid proved to be one effective way of improving the system overall performance. Nano fluid is a new working fluid used in heat exchanger which is eco- friendly because it uses water as a base fluid. Nanofluids are prepared by suspending metallic or non-metallic nanometer dimension particles in base fluid (water, oil and ethylene glycol). So, the nanofluid is used as a working fluid in the pulsating heat pipe and analyzed the improvement of performance.

EXPERIMENTATION

a. Preparation of nanofluid

Nanofluid is produced by metal or metal oxide nanoparticles suspended in base fluids such as oil or water. It involves many methods such as changing the pH value of the suspension, using surfactant activators, and using ultrasonic vibration. The nanoparticles suspended in base fluids are stable for a long time. For this research, nanofluid was prepared by a sonicator for one hour. The sonicator had a probe type, operating frequency, and power source of 20 kHz, AC100, and 120V/AC220 240V 50/60 Hz, respectively. The Al2O3 nanopowder used in this study has a particle size of 50 nm and purity of 99.5%. The Al2O3 nanoparticles were suspended into DI water with concentrations of 0.25%, 0.5%, 0.75%, and 1 %w/v. Stability was up to 48 hours. Nanofluid for experimentation was prepared in Unique traders, Nagpur.

b. Experimental Setup

Figure1 illustrates the experimental setup, consisting of a closed loop PHP assembly with double turn, having a control panel. The CLPHP is divided in three main sections:

- The evaporator zone, where the device receives a controlled heat input by means of oil bath heaters.
- The adiabatic zone ideally insulated from the environment.
- The condenser zone where the PHP releases the heat by means of a liquid cooled heat sink

The tubes in the three sections (*i.e.* evaporator, adiabatic and condenser) are made of copper in order to minimize the thermal resistance between the tube and the heat input/output zones while the straight tubes in the adiabatic section are covered with insulated material so that there is no contact with the environment.

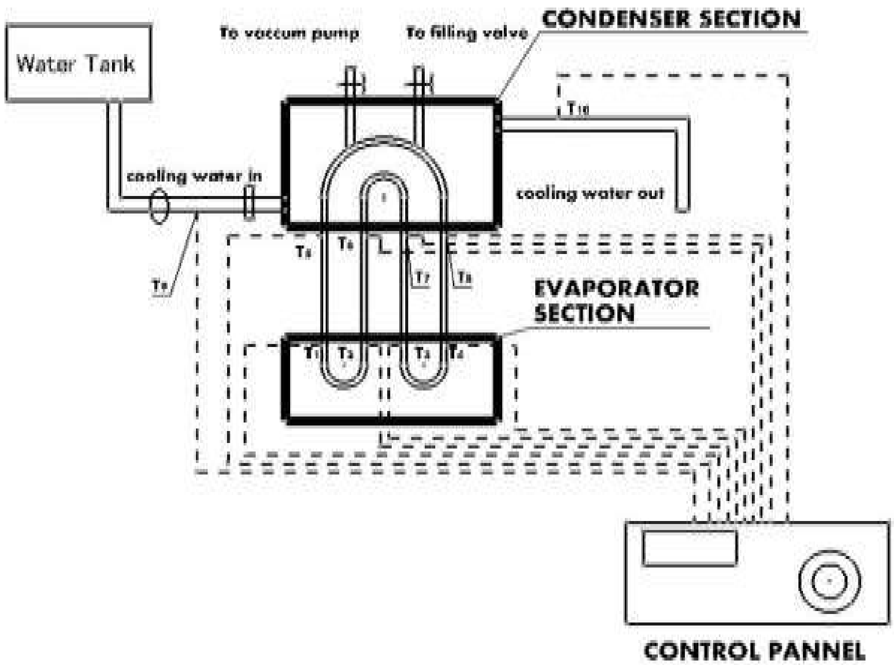

Fig. 1 Schematic of the Experimental Setup

Figure 1 shows the Experimental setup. All copper tubes have 4.0 mm O.D. and 3.0 mm I.D. Two smaller copper tubes (4 mm O.D., 3 mm I.D.) has been brazed on the main tube of the condenser section in order to connect the vacuum/filling valve and pressure indicator. In the evaporator section oil bath is used. Oil bath is made of aluminum sheet having dimension 11×7×23 cm^3. It is heated with press coil of 500 Watt. This whole assembly is insulated with glass wool then it is enclosed with plywood structure. The adiabatic zone is made of four straight copper tubes. The straight tubes in the adiabatic section are covered with insulated material (Cotton rope) so that there is no contact with the environment. All copper tubes have 4.0 mm O.D. and 3.0 mm I.D. Two copper tubes (4.0 mm O.D., 3.0 mm I.D.) has been brazed on the main tube of the condenser section in order to connect the vacuum/filling valve and pressure indicator. The condenser section was cooled by (coolant) normal water with maintained flow 50 ml/min and inlet and outlet temperature measured. The copper tubes in the condenser section are embedded into a shell made of transparent acrylic plate's Four holes allow the copper tube branches to come out the shell and connect with the adiabatic section, cooling water is kept at constant flow 50 ml/min circulated through the condenser.

c. Experimental Procedure

- The first step is to create a vacuum inside the tube. In order to create vacuum inside the PHP, a reciprocating vacuum pump is connected to the filling valve.
- Thereafter the device is fill with the desired working fluids and closed the valve.
- Water was supplied from storage tank to the condenser section. Wait till the condenser tank is completely filled. Then flow rate was measured with beaker and stop watch.
- Switch on the control panel and set appropriate power supply for oil bath with the help of dimmer stat.
- Oil in oil bath starts heating. This in turn heats the evaporator section.
- Provide a constant heat input to the oil bath up to steady state reached and temperature at different points of CLPHP note down between 10-minute intervals.
- The heat input is increased with step of 10 W input powers after steady state reached. After a quasi-steady state was reached, note down the readings.

2. At steady state from the inlet - outlet temperature and mass flow rate of the coolant, the heat transfer could be calculated. Above procedure was repeated for the different working fluids.

DATA REDUCTION

Average temperature of evaporator and condenser are used to calculate the thermal resistance for test of CLPHP by using equation as:

$$R_{th} = \frac{Te - Tc}{Qin}$$

Where,

R_{th} - Thermal resistance

T_e - Average temperature of evaporator

T_C - Average temperature of condenser Q_{in} – Heat input (V×I)

The cooling capacity of condenser is calculated from the following equation

$$Q_{out} = m\, c_p\, (T_{out} - T_{in})$$

Where,

Q_{out}= Heat output (W)

m= mass flow rate of water (kg/s)

C_p= specific heat capacity of water (J/Kg-K) T_{out}= outlet temperature of water (^oC)

T_{in}= inlet temperature of water (^oC)

RESULT AND DISCUSSION

From the experimental analysis, graphs are plotted showing effect of different concentration of Al_2O_3/water nanofluid and pure water on average evaporator temperature, average condenser temperature and thermal resistance with different heat inputs as shown in figure 2, 3 and 4 respectively. With increasing heat inputs to the device, the evaporator temperature rises resulting in a greater density gradient in the tubes. Simultaneously the liquid viscosity also drops diminishing the wall friction and it proportionally to heat input therefore thermal resistance decrease with increase in heat input for all working fluids.

Figure 2 shows the change in average evaporator temperature of PHP for various heat in-puts as well as different concentration values of Al_2O_3/water nanofluids and pure water. Average evaporator temperature increases with increasing heat load and decreases as increase in mass concentration of nanofluid. It is due to the higher saturation temperature and high specific heat of water. As concentration of nanoparticles in water increases saturation temperature and specific heat of water decreases tends to decrease in evaporator temperature. Minimum evaporator temp is obtained for 1%w/v Al_2O_3/water nanofluid.

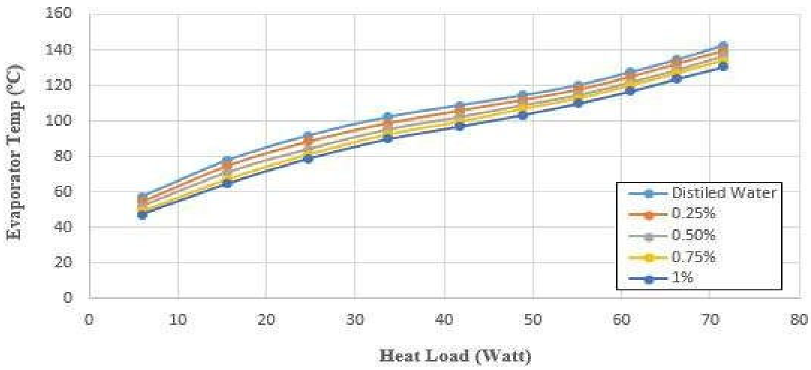

Fig. 2 Average Evaporator Temperature Vs Heat input of water and nanofluid PHP

Figure 3 shows the change in average condenser temperature of PHP for various heat inputs as well as different concentration values of Al_2O_3/water nanofluids and pure water. Aver-age condenser temperature increases with increasing heat load and increase as increase in mass concentration of nanofluid. Because thermal conductivity of fluid is increases due to addition of Al_2O_3 nanoparticles, hence more heat is transported towards condenser section.

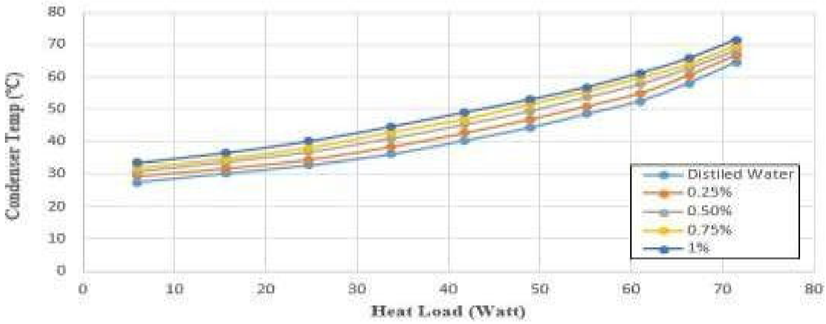

Fig. 3 Average Condenser Temperature Vs Heat input of water and nanofluid PHP

Figure 4 shows the change in thermal resistance of PHP for various heat inputs as well as different concentration values of Al_2O_3/water nanofluids and pure water. Thermal resistance decreases with increasing heat load and decreases with increase in mass concentration of nanofluid. It is due to the presence of nanoparticles in base fluid. This increases thermal conductivity of base fluid. Reason for enhancement of thermal conductivity is microconvection between solid and liquid molecules, Brownian motion of nano size particles and clustering in nanofluids.

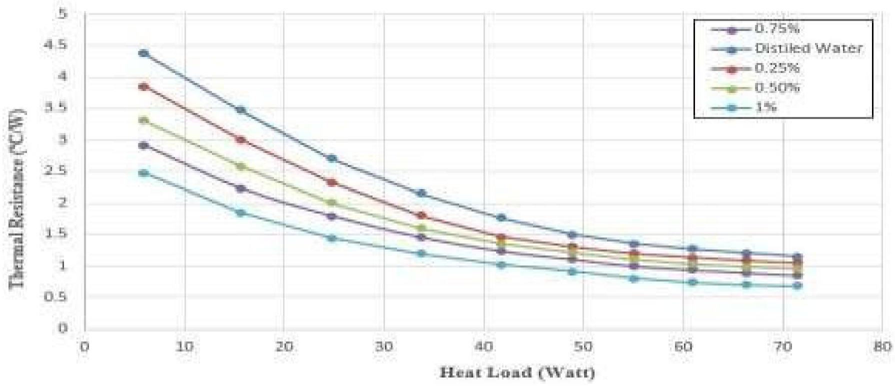

Fig. 4 Thermal resistance of water and nanofluid PHP

CONCLUSION

Form this experiment studies, following conclusion are drawn:

- Al_2O_3/Water nanofluid PHP gives better thermal performance than pure water PHP
- For all concentration of nanofluids and water PHP thermal resistance decrease with in-crease heat input.
- Thermal performance of PHP strongly depends on thermo physical properties of working fluids.
- Thermal resistance decreases with increase in mass concentration of Al_2O_3/water nanofluid.
- Minimum value thermal resistance 0.829 °C/W is obtained for 1%w/v concentration at 72W heat input.

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