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Influence of Gravity on the Performance of Closed Loop Pulsating Heat Pipe

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***Abstract*—**Closed Loop Pulsating Heat Pipe (CLPHP) is a passive two-phase heat transfer device having potential to achieve high heat transfer rates over conventional cooling techniques. It is found in electronics cooling due to its outstanding characteristics such as excellent heat transfer performance, simple, reliable, cost effective, compact structure and no external mechanical power requirement etc. Comprehensive understanding of the thermo-hydrodynamic mechanism of CLPHP is still lacking due to its contradictory results available in the literature. The present paper discusses the experimental study on 9 turn CLPHP. Inner and outer diameters of the copper tube are 2 mm and 4 mm respectively. The lengths of the evaporator, adiabatic and condenser sections are 40 mm, 100 mm and 50 mm respectively. Water is used as working fluid. The Filling Ratio (FR) is kept as 50% throughout the investigations. The gravitational effect is studied by placing the evaporator heater at different orientations such as horizontal (90 degree), vertical top (180 degree) and bottom (0 degree) as well as inclined top (135 degree) and bottom (45 degree). Heat input is supplied in the range of 10-50 Watt. Heat transfer mechanism is natural convection in the condenser section. Vacuum pump is used to evacuate the system up to 10^{-5} bar. The results demonstrate the influence of input heat flux and gravity on the thermal performance of the CLPHP.

***Keywords*—**Closed loop pulsating heat pipe, gravity, heat input, orientation.

I. Introduction

PULSATING Heat Pipe (PHP) is a serpentine channel of capillary size. It is evacuated and partially filled with working fluid. Formation of liquid slug and vapor plug are observed due to the dominance of surface tension force. It consists of evaporator, adiabatic section and condenser. The supply of heat to evaporator increases the vapor pressure in the evaporator. It pushes the liquid slug to the condenser. Vapor plug and liquid slugs are cooled in the condenser which reduces the condenser pressure. Pressure difference between evaporator and condenser becomes the driving force and initiates the pulsation inside PHP. PHP is first proposed and patented by Akachi [1]. Many researchers afterwards carried out experiments on PHP. PHP finds its application not only in electronic cooling [2]; but several others such as heat transfer tool in a solar water heater [3], air conditioning system [4], hybrid vehicle [5], fuel cell cooling technology [6], heat exchanger [7] and radiator [8]. However, PHP has many unresolved issues so far and needs to be investigated or reinvestigated [9]. These issues are sensible heat versus latent heat, optimum charge ratio, gravitational effect, number of turns, losses at bends, onset heat flux/temperature, evaporator dry out, surface tension, non-dimensional parameters, numerical simulations and nanofluid PHP. Moreover, there is no clear definition of macro-to-minichannel transition criteria in literature. Since PHP uses capillary size channels, it is very essential to investigate the influence of gravitational force over surface tension force. Few studies are available in literature which addresses this issue but results are found conflicting [10]-[14]. This motivates the authors to investigate the gravitational effect on the performance of PHP. The present paper is an extensive work of Mehta et al. [15] where the influence of FR and heat flux on startup mechanism and performance are investigated. The aim of the present study is to develop the experimental setup to accommodate various orientations of the PHP and to investigate the effect of gravity on the performance of PHP with heat input in the range of 10-50 Watt.

II. Experimental Set Up

The experimental setup is developed to investigate the effects of heat input and orientation on performance of CLPHP as shown in Fig. 1. Inner and outer diameters of the copper tube are considered as 2 mm and 4 mm respectively. Inner diameter is selected less than the critical diameter of CLPHP for water in order to set the dominance of surface tension force over gravitational force. The lengths of the evaporator, adiabatic, and condenser sections are considered as 40 mm, 100 mm, and 50 mm respectively. Pitch between each turn is set as 20 mm and total 9 turns are considered. Two non-return valves are provided to the outer copper tube. One valve is used to connect the vacuum pump and second valve is used to fill and remove the working fluid. Vacuum pump (HINDHIGH VAC Make) consists of a rotary pump with Pirani gauge is used to evacuate the system up to 10^{-5} bar. Total volume of 9 turn CLPHP is calculated by measuring weight of completely displaced water from fully filled copper tube. Total volume is measured as 17 milliliter. The charge ratio of 50% is set by inducting water of 8.5 milliliter through syringe attached with one of the non-return valves. Evaporator section is constructed using aluminum block of size 260 mm x 25 mm x 50 mm with different slots and circular holes. Cartridge heaters (10 mm diameter, 40 mm length) are fitted into circular holes to provide uniform heating. Copper tubes are firmly fitted in the slotted portion. Aluminum is selected

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due to its high thermal conductivity and good machinability property. To avoid heat loss to the atmosphere, a thick layer of insulating material (glass wool) is wrapped around aluminum block covering from all the sides. Adiabatic section is also covered with glass wool to prevent heat loss. Heat transfer mechanism is selected as natural convection in the condenser section. Heat input to the evaporator section is controlled through control panel. It consists of dimmer (0 watt to 270 watt), digital ammeter (0 ampere -5 ampere) and digital voltmeter (0 volt to 516 volt). The temperature scanner (ENVADA make) is used to record data for every 2 seconds (minimum possible sampling time with the existing setup) for all thermocouples. All temperature reading data are logged to the computer through e-scan software. CLPHP is mounted on a tilt-able frame wherein different holes are drilled at every 15° angle. Required angular position of the CLPHP adjusted through simple nut and bolt arrangement. Fig. 2 shows the different orientations of the CLPHP obtained for the investigations.

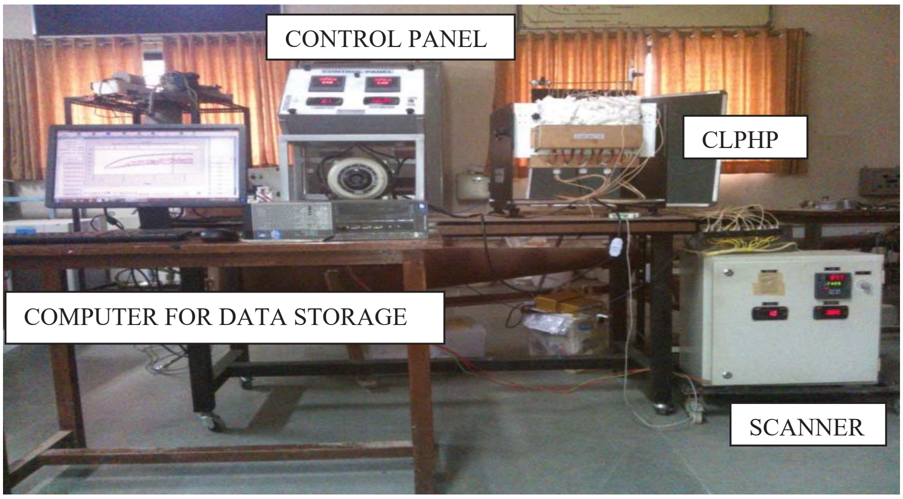


Fig. 1 CLPHP experimental setup

III. Experimental Procedure

The experimental procedure is laid down as follows:

1. Orientation of the CLPHP is set by tilt-able table.
2. Copper tube is made empty and moisture free.
3. The system is evacuated by vacuum pump at desired vacuum.
4. Known quantity of working fluid is inserted into the system.
5. Heat input is applied with the help of control panel.
6. Data logging system is started.
7. The experiment is performed till the steady state obtained.
8. The same process is repeated for different heat input and orientations.

IV. Experimental Analysis

This section discusses the experimental observations. The FR of water is kept 50% throughout the investigations. The gravitational effect is studied by placing the evaporator heater at different orientations such as horizontal (90^0), vertical top (180^0) and bottom (0^0) as well as inclined top (135^0) and bottom (45^0). Heat is supplied in the range of 10-50 watt. Heat transfer mechanism is natural convection in the condenser section. Vacuum pump is used to evacuate the system up to 10^{-5} bar. Total 13 thermocouples are installed to measure temperatures. Out of 13 thermocouples, 5 thermocouples are used for evaporator temperature, 7 thermocouples are used for condenser temperature and 1 thermocouple is used for ambient temperature. The ambient temperature is observed 29°C during experiment. The calculations are performed through (1)-(4).

Average evaporator temperature, $T_e = \frac{1}{5}\sum_{i=1}^{5} T_i$ (1)

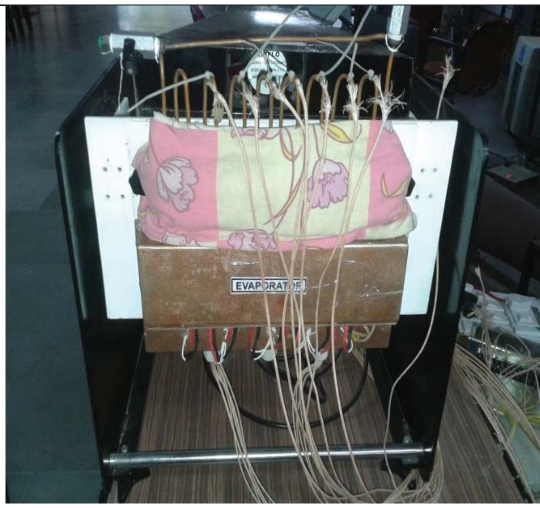
Average condenser temperature, $T_c = \frac{1}{7}\sum_{i=1}^{7} T_i$ (2)

Total heat supply, $Q = V * I$ (3)

Thermal resistance, $R = \frac{T_e - T_c}{Q}$ (4)

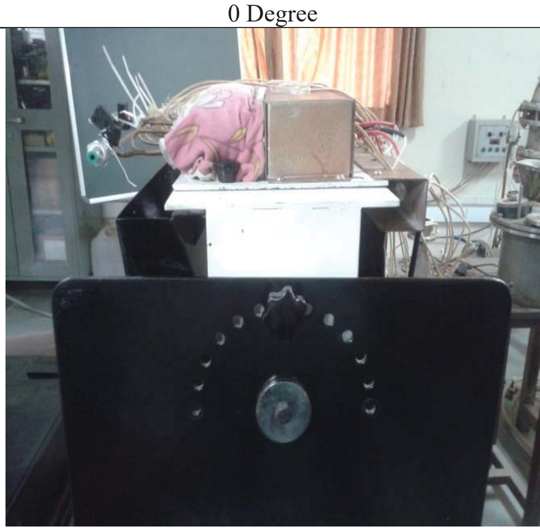
Repeatability test is performed to check the stability of experimental results. Test is performed at four different time keeping constant heat input as 30 watt and constant orientation as vertical bottom heating (90°). The evaporator and condenser steady state temperature are observed about 80°C and 60°C respectively during each time.

Orientation of CLPHP	Degree
vertical bottom heater	0 degree
inclined bottom heater	45 degree
horizontal	90 degree
inclined top heater	135 degree
vertical top heater	180 degree



0 Degree

45 Degree



90 Degree

135 Degree

180 Degree

Fig. 2 Various Orientations (0^0 To 180^0) of CLPHP

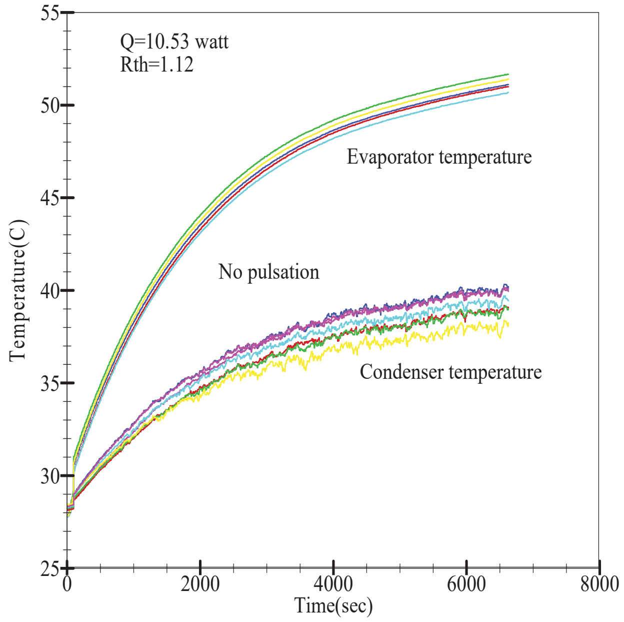


Fig. 3 Evaporator and condenser temperatures at 10.53 Watt

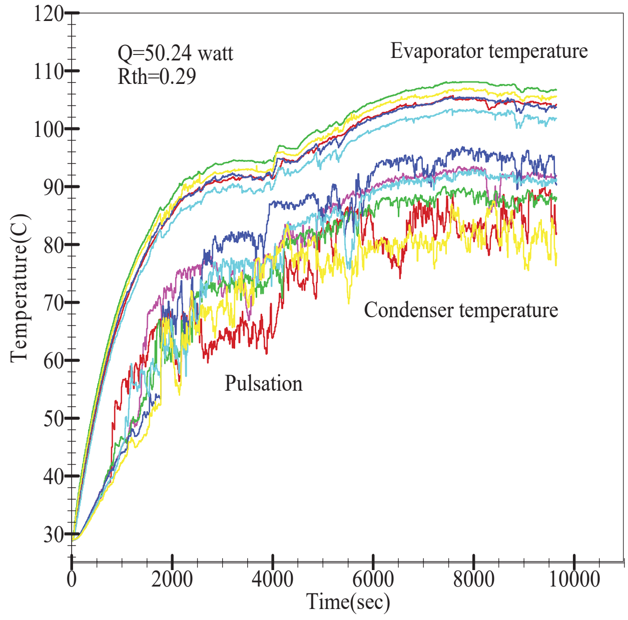


Fig. 4 Evaporator and condenser temperatures at 50.24 Watt

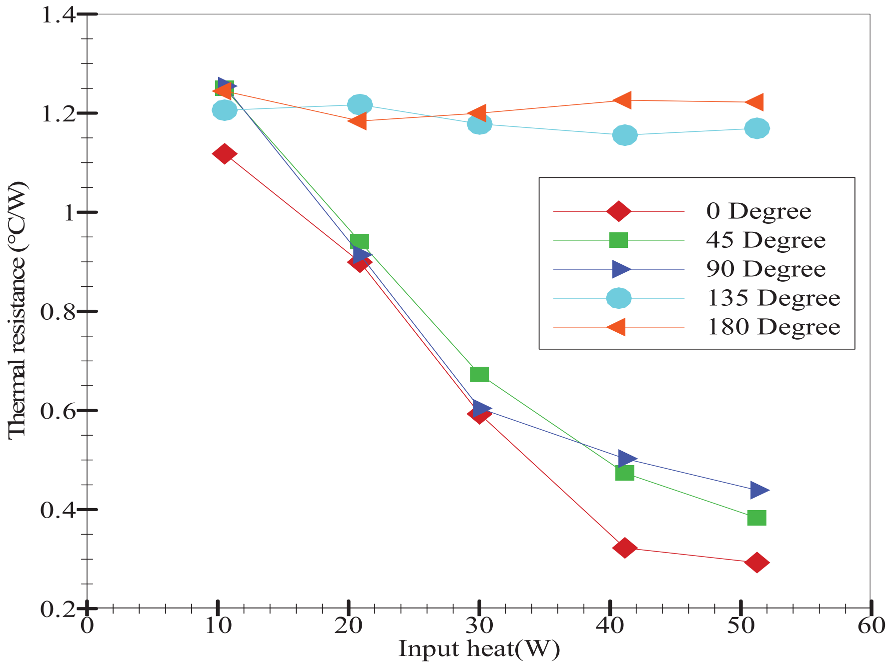


Fig. 5 Input heat versus thermal resistance for different orientations

The influence of heat input on condenser and evaporator temperatures is shown in Figs. 3, 4. At lower heat input of 10 W, pulsations are not observed (Fig. 3). Heat is not transferred from evaporator to condenser. Heat is accumulated in the evaporator. Hence, the evaporator temperature is observed to increase with time. There is a large temperature difference between evaporator and condenser temperatures. From (4), large temperature difference between evaporator and condenser for small heat input leads to high thermal resistance (R_{th}=1.12 at Q=10.53 watt). Increase in input heat (50 W), pulsations are clearly observed as shown in Fig. 4. Liquid slug and vapor plugs are moved from evaporator to condenser and transferred heat from evaporator to condenser. There is less temperature difference observed between condenser and evaporator.

The influence of orientations on the performance of CLPHP is shown in Fig. 5. There is no pulsation observed at 135° and 180° orientations during 0 to 50 Watt heat input. Pulsations are observed only for 0°, 45° and 90° orientations. It is also observed that increase in heat input decreases the thermal resistance and hence improves the performance of the CLPHP for 0°, 45° and 90° orientations. This shows the pulsating behavior of CLPHP. This trend is not observed for 135° and 180° orientations which represent pulsation free system. At lower heat input (20 and 30 watt), vertical bottom heater (0°) and horizontal orientation (90°) give almost similar performance. A little higher thermal resistance is observed for inclined bottom heater (45°). At inclined bottom heater (45°), pulsations observed in just two and three thermocouples out of seven for 20 watt and 30 watt respectively. While in case of vertical bottom heater (0°) and horizontal orientation (90°), all thermocouples indicate pulsations. Initial pressure distribution in CLPHP is thought of to play an important role for the performance of CLPHP at lower heat input. At higher heat input, heat is enough to break the initial pressure distribution. Gravity helps liquid slugs to return evaporator section. It enhances pressure difference between evaporator and condenser. Therefore, vertical bottom heater (0°) gives minimum thermal resistance at 40 watt and 50 watt. Horizontal orientation (90°) give maximum thermal resistance and inclined bottom heater (45°) give performance in between vertical bottom heater (0°) and horizontal orientation (90°) at higher heat input (40 watt and 50 watt).

V.Conclusion

The following conclusions can be drawn from the present experimental investigations on CLPHP.

1. 10-watt heat input is not sufficient to start pulsation for 50% FR.
2. As heat input increases, thermal resistance decreases.
3. CLPHP fails to operate at inclined top heater (135°) and vertical top heater (180°). It successfully performs at vertical bottom heater (0°), inclined bottom heater (45°) and even at horizontal orientation (90°).
4. Initial pressure distribution in PHP could be significant to start pulsation at lower heat input.
5. Gravity is observed to play an important role and hence at higher heat input, vertical bottom heater (0°) orientation gives better performance than others orientations.

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