EFFECT OF FIN ON THE PERFORMANCE CHARACTERISTICS OF CLOSE AND OPEN LOOP PULSATING HEAT PIPE

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ABSTRACT

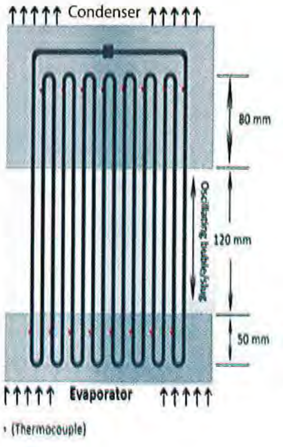
Pulsating heat pipe (PHP) is a two-phase thermal control device with arbitrary number of turns which is basically used for the thermal management of microelectronic devices as there is a requirement of miniaturization of heat exchangers. To fulfill today's increasing demand of power electronic applications PHP is a proven technology which works on principle of oscillation of the working fluid and phase change phenomenon in a capillary tube. An experimental investigation has been done on both close and open loop pulsating heat pipes by using suitable working fluid to observe their thermal performance. It has been performed on 2 mm inner diameter and 2.5 mm outer diameter open and close loop pulsating heat pipe with fin added on the condensation section. The overall experiment is done by using methanol with 50% filling ratio at 0° (vertical) inclination angle on close loop pulsating heat pipe (CLPHP) and open loop pulsating heat pipe (OLPHP) with 8 loops. In both the pipe evaporation section is 50mm, adiabatic section is 120 mm and condensation section is 80 mm. The main objective of this experiment is to observe the effect of their thermal performance while using fins and without fin i.e. the basic form. The paper attempts theoretical and experimental investigation on the thermo-physical properties of working fluid and will also show the result regarding the significance of using fin on CLPHP and OLPHP. Keywords: PHP, CLPHP, OLPHP, fin with condensation section.

Key Words: Anaerobic treatment, Hydrogen and Methane generation, Reactor Configuration

1.0 INTRODUCTION

Conventional heat pipes are heat transfer device that combines the principles of both thermal conductivity and phase transition. To cope up with present demand of increased capacity of heat transfer devices, PHP have emerged as interesting alternatives to conventional heat transfer technologies which have been introduced by Akachi et al. [1,2] in the 1990's and can be divided into two major groups known as CLPHP and OLPHP. A generation of researches have directed by S. Khandekar et al. [3] and M. Groll et al. [4] filled with required quality of fluid.

The present investigation is done with fin or extended surface in condenser section at 0^0 (vertical) inclination angle using working fluid methanol with 50% filling ratio on CLPHP and OLPHP with 8 loops. The whole device is divided into three parts known as evaporator, adiabatic and condenser section. The condensation section is placed in upper portion and the evaporator section is placed in lower portion so that liquid may go downward due to gravitational force. As a result of heat absorption by evaporator and heat release by condenser, vapor bubbles are observed inside of a micro-machined channel. After heat dissipation, it moves back to evaporator. In previous experiments, it was thought that sensible heat is main reason for this, stated by M. Groll et al. [4], Nisho et al. [5] and Shafii et al. [6] but the concept has been changed later by S. Khandekar et al. [7].



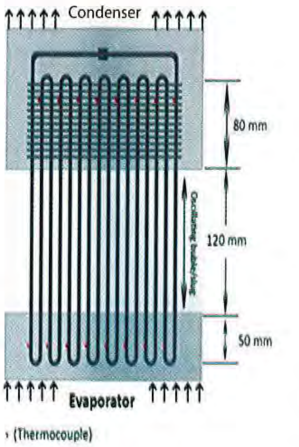
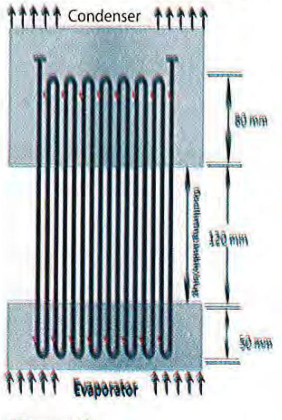


Fig. 1: Normal CLPHP **Fig. 2: Finned CLPHP**

In our experiment, a new idea of fin on CLPHP and OLPHP is investigated here at 0^0 angle (vertical) by filling arbitrary tubes with methanol. Fin is basically used here to increase the rate of heat transfer to the environment by increasing convection. The amount of conduction, convection, or radiation of an object determines the amount of heat it transfers. Effect of fin in case of pulsating heat pipe is not examined before. Present investigation is done to show the effect of fins on CLPHP and OLPHP which is a strong demand for heat augmentation techniques.



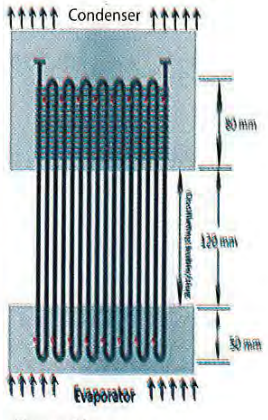


Fig. 3: Normal OLPHP **Fig. 4: Finned OLPHP**

2.1 Experimental Setup

The experimental setup is shown in Figs. 1-4. The setup consists of a meandering heat pipe (ID: 2mm, OD: 2.5mm, L: 25cm, material: copper), creating a total of 8 turns. The heat pipe is divided into 3 regions- the evaporator (5cm), adiabatic section (12cm) and the condenser section (8cm). The 2mm copper wire of 2mm is used in condenser section at equal distance as fin in finned CLPHP and OLPHP. The number of thermocouples are 6 (LM-35sensors, Local Sensor Accuracy (Max) (+/- C): 0.5, range: -55°C to +150°C) which are glued to the wall of heat pipe in evaporator and condensation section; 3 for each sections. Evaporator section is insulated inside a box of wood frame, separated from outside using mica sheets with Nichrome wire (diameter = 0.25 mm, resistivity: 1.0×10^{-6} Ù-m, specific heat: 450 Jkg^{-1}K^{-1}) wounded inside, which is heated by a power supply unit (AC, 220V, 50Hz) via a variac (3F, 300V, 60 Hz). Methanol is used as working fluid at the amount of FR 50% (by volume) for each setup. For cooling the working fluid, forced convection is used by a DC fan. The whole apparatus is set on a wooden test stand (wood frame) with provision of angular movement of the PHP using servo motor (Modulation: Analog, Speed: 0.20 sec/60°, Weight: 1.94oz (55.0 g), Dimensions: Length: 1.60 in (40.6 mm), Width: 0.78 in (19.8 mm), Height: 1.69 in (42.9 mm), Motor Type: Coreless, Gear Type: Metal, Rotation/Support: Dual Bearings, Rotational Range: 180°, Pulse Cycle: 20 ms, Pulse Width: 1000-2000 ìs). For data collection Arduino Mega (Microcontroller: ATmega1280, Operating Voltage: 5V, Input Voltage (recommended): 7-12V, Analog Input Pins: 16) is used. For avoiding complicacy, working fluids are incorporated in the heat pipe manually. The other accessories of the setup are adapter circuit, selector switches etc.

2.2 Experimental Procedure

- After the construction of the whole setup the experiment is carried out.
- The experiment is performed for finned and un-finned condenser sections with 50% filling ratio of Methanol as working fluid for both close loop and open loop pulsating heat pipe.
- First the heat pipe is filled 50% by working fluid Methanol (injecting by syringe) keeping the PHP in vertical (0°) position for both finned and un-finned condenser CLPHP and OLPHP.

- Different heat inputs were provided to the system and temperatures reading of different sections were measured by thermocouples using Arduino Mega.
- For cooling the condenser a cooling fan is used. It is connected to an adapter circuit.

3.0 RESULTS AND DISCUSSION

An experiment is carried out for methanol at 0^0 (vertical) inclination angle on CLPHP and OLPHP of finned and un-finned heat pipe where fin is used in condenser section. In this research, the value of thermal resistance is considered as an indication of efficiency, i.e. higher value of R_{th} refers to higher difference of temperature between evaporator and condenser section and eventually indicates a higher efficiency of the system. Result is compared between finned and un-finned structure on basis of different characteristics.

3.1 Variation of Temperature with Time

In all the experimental conditions, the variation of temperature with time curves shows a similar pattern. These typical curves are presented in Figs. 5, 6, 7 and 8 which are taken at 0° inclination for 50 W heat input with methanol as working fluid. For all the experimental cases, the curves at first increase rapidly with time and then the rate of increase become slow to some extent. This is same for all the temperature data; i.e. for evaporator and condenser section. But, certainly, the rate of increase is different for different regions. After reaching the boiling point, the temperature increase in evaporator slows down due to the heat required in phase temperature with time at 0 degree for 50 W heat input transfer.

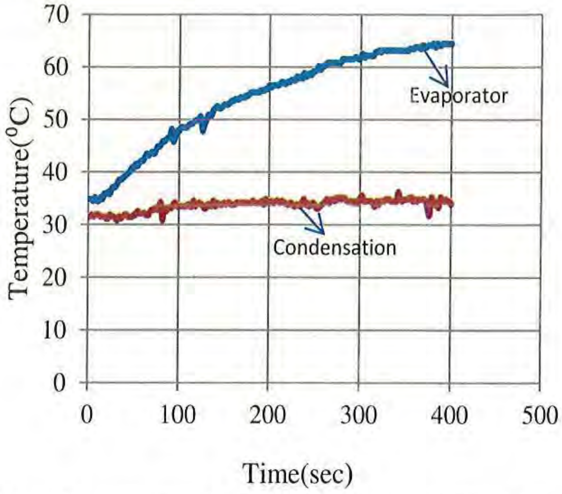


Fig. 5: Variation of close loop normal structure

Temperature increase rate being slow in the condenser section can be attributed to the fact that, at some point of time, it becomes close to the room temperature. So no further need of cooling is then necessary. From each figure it is clear that till first 200 seconds there is a higher increase rate of evaporator temperature but after 200 seconds the rate decreases.

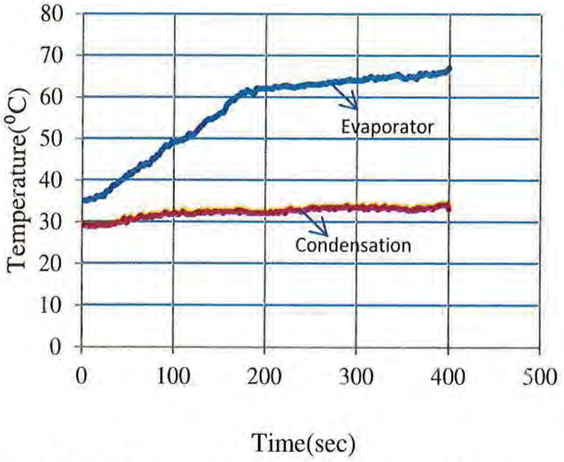


Fig. 6: Variation of close loop finned structure temperature with time at 0 degree for 50 W heat input.

In finned structure steady condition is achieved more early than un-finned structure in between 200 seconds on both CLPHP and OLPHP. This indicates faster heat transfer rate in finned structure. Higher difference of temperature between evaporator and condenser section indicates higher efficiency of the system. In finned structure it is found around 34°C (max) for close loop and 32°C for open loop whereas in un-finned structure it is around 30°C (max) for close loop and 28°C for open loop. Fin provides extended surface in condenser section that increases heat transfer rate through convection as a result it makes the condenser region temperature low with better working efficiency. It also shows that close loop structure performes better than open loop structure specially finned CLPHP as for the same loops CLPHP provides more area in condensation section than OLPHP. This increases flow area of bubble that carries heat and consequently it increases heat transfer in structure.

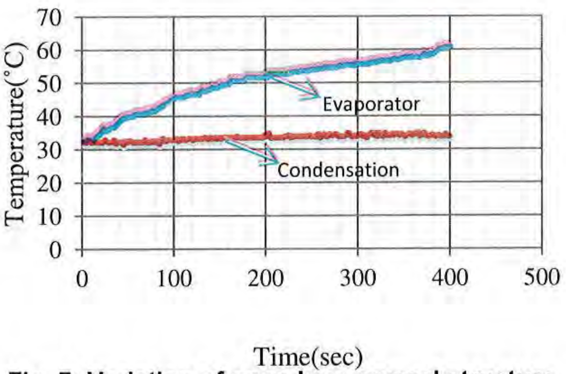


Fig. 7: Variation of open loop normal structure temperature with time at 0 degree for 50 W heat input

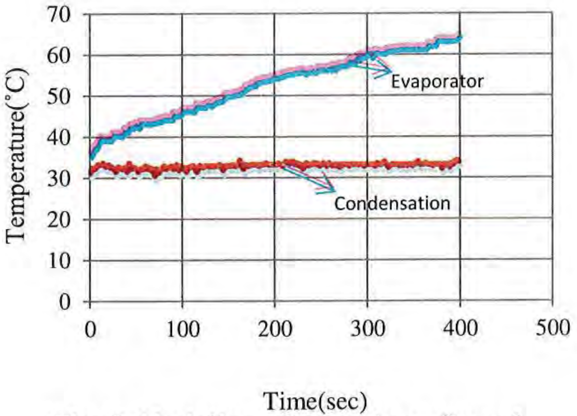


Fig. 8: Variation of open loop finned structure temperature with time at 0 degree for 50 W heat input

3.2 Variation of thermal resistance

Thermal resistance is considered in this paper as an indicator of heat pipe effectiveness. It is defined as the ratio of difference in average temperature of evaporator section and average temperature of condenser section for any instance to the heat input at that time. The thermal resistance of PHP is given by

$$R_{th}=(T_e-T_c)/Q$$

The equation indicates the variation of resistance experience in the system. The curves of thermal resistance are of similar pattern for all the cases. They are maximum at minimum heat input and minimum at maximum heat input; i.e. the thermal resistance has an inverse relationship with heat input. These curves follow an exponential pattern and typical graphs are shown in Figs. 9-11, for 0° inclination (vertical position). But, the fall of thermal resistance is not of the same rate for all cases, it varies up to some extent. In finned structure, for both CLPHP and OLPHP R_{th} is higher than unfinned structure for all cases of heat input. As we have already mentioned that higher resistance means higher efficiency, so we can state that finned structure exhibits better performance than normal structure. We can also state that finned close loops show better performance than finned open loop as shown in Fig. 11. This shows close loop to be better heat transfer medium than open loop structure.

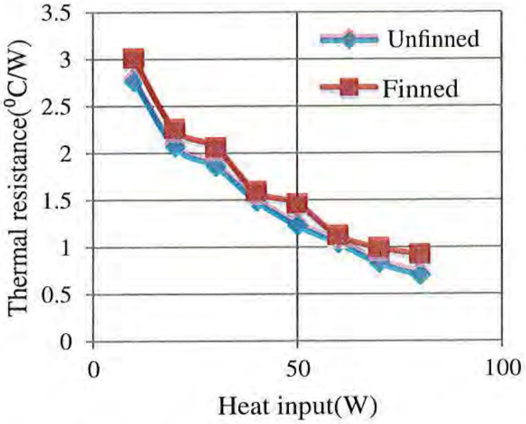


Fig. 9: Variation of thermal resistance with heat input at 0 degree position (CLPHP)

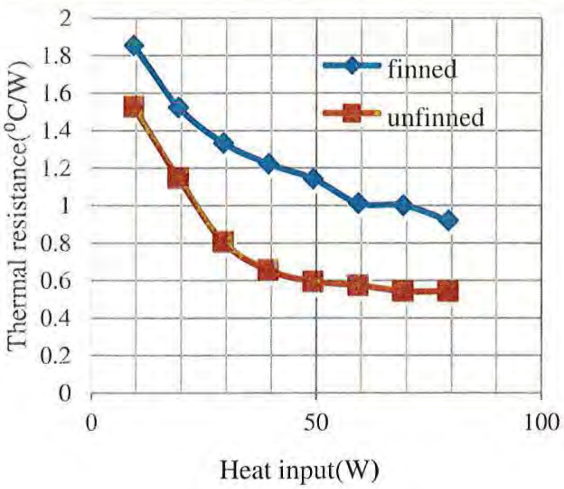


Fig. 10: Variation of thermal resistance with heat input at 0 degree position (OLPHP)

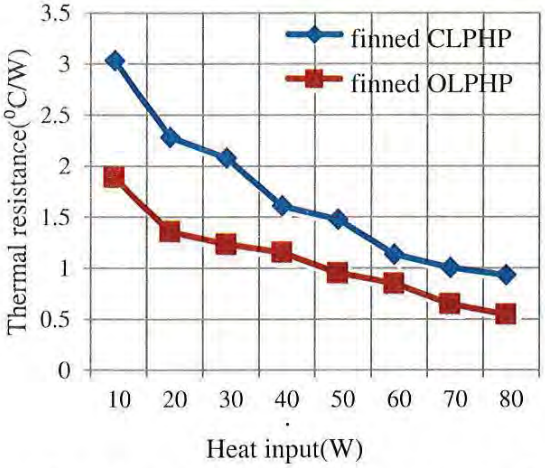


Fig. 11: Variation of thermal resistance of finned structure with heat input at 0 degree position for both CLPHP and OLPHP

4.0 CONCLUSION

Both closed loop pulsating heat pipes and open loop pulsating heat pipes are complex heat transfer systems with strong thermo-hydrodynamic coupling governing the thermal performance. Different heat input to these devices give rise to different flow patterns inside the tubes. This in turn is responsible for various heat transfer characteristics. The study strongly indicates that design of these devices should aim at thermo-mechanical boundary conditions which resulting convective flow boiling conditions in the evaporator leading to higher local heat transfer co-efficient. In this research, best performance is obtained from finned structure than normal structure in the experiment for both close and open loop but from them close loop exhibits better heat transfer characteristics then open loop. This result indicates the advantages of close loop PHP over open loop PHP though more experiment is required to justify the advantages with more variation of different parameters i.e. inclination, fluid, filling ratio, using fin with different designs etc.

Nomenclature

R : thermal resistance, °C/W
T : temperature along the heat pipe, °C
ÄT : temperature drop along the device, °C
L : length of heat pipe, cm
IA : Inclination angle, °
Q : heat input, W
D : diameter of heat pipe, mm
FR : filling ratio, %
L : Characteristics length
OD : Outer diameter of tube
ID : Inner diameter of tube
th : thermal
a : adiabatic section
e : evaporator section
c : condenser section

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