Effect of Number of Turns on Performance of A Closed Loop Pulsating Heat Pipe

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Abstract: **Closed loop pulsating heat pipe is a small heat transfer device especially suited for thermal management of electronic application. PHP is a cooling device made of a long capillary tube, which forms a continuous structure and operates by the pulsation and phase change of its working fluid. The unique feature of CLPHP compared with conventional heat pipe is that, there is no wick structure to return the condensate to the evaporator section, thus there is no counter flow between the liquid and the vapour. An experimental investigation on pulsating heat pipe will be conducted. The PHP consists of multi turns (single, two, three and four turn) made up of copper tube has an inside diameter of 2mm and a wall thickness of 0.5mm. The transient and steady state experiments are conducted for various heat loads, at 50% filling ratio and 90^0 orientations. Ammonia was used as working fluid during the experimentation. The performance quantities of PHP like thermal resistance are evaluated. The result shows that, the thermal resistance decreases rapidly with the increase of the heating input from 10 to 22 W. From the experiment it is seen that, lower value of thermal resistance 1.06 ^{0}K/W is obtained for four turns.**

Keywords: Ammonia, pulsating heat pipe, multi turns etc

1. INTRODUCTION

The pulsating (or) oscillating heat pipe (PHP), first introduced by Akachi [1], has demonstrated to be a promising solution for future heat flux management and applications and is especially useful for its comparatively long distance transport ability. Unlike traditional, coaxial heat pipes, the PHP is wickless, featuring a variety of form factors, and is easier to manufacture and possesses fewer operating limitations [2]. It is known that conventional heat pipes with wick structures are widely used to manage thermal problems of electronic products such as laptop computers, servers and power electronic components [3]. The Pulsating Heat Pipe (PHP) is a passive two-phase heat transfer device suitable for low power applications such as the cooling of electronics. In spite of its name both structure and working principles are very different with respect to the standard heat pipe: it can be in the form of a open loop PHP or Closed Loop PHP, shown in Fig. 1. In both cases it consists of a capillary tube, usually made of copper, bended in many turns, which is firstly evacuated and then partially filled with a working fluid. Due to the capillary dimensions, the working fluid distributes itself naturally inside the tube as an alternation of liquid slugs and vapor plugs. Moreover, since the fluid is in saturated conditions, the thermal power provided by the hot source to the heating section causes the evaporation of the thin liquid film which surrounds each vapor plug. The vapor expansion pushes the adjacent liquid towards the condenser where the adsorbed heat can be released to a cold sink. If the tube is closed end-to-end in a loop the fluid can both oscillate and circulate inside the tube while in the CLPHP the fluid can only oscillate [4].

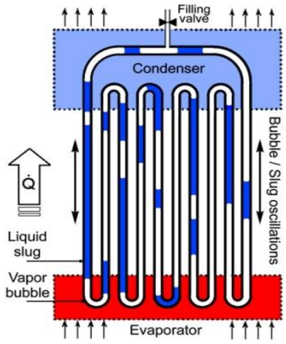

Fig.1. Schematic representation of pulsating heat pipe

A vertical, closed loop, copper PHP with Ethanol as the working fluid is first experimentally investigated by Sameer Khandekar et.al. [5]. Further, an Artificial Neural Network (ANN) is then trained with the available test data and subsequently validated. Later, Experimental studies were carried out to understand the heat transfer characteristics of pulsating heat pipes by Guoping Xu et.al. [6] in their study, two heat pipes with different working fluids of HFC-134a and butane are evaluated. Water was selected as the working fluid of the heat pipe system developed by Akyurt et.al. [7]. Researchers have shown that geometry and design material of PHP are key issues influencing its thermal behavior. Counting the geometry effects; number of turns, total length of the tube, tube diameter, and the height of whole system should be considered [8].

2. DESCRIPTION OF THE EXPERIMENT SET UP

The PHP's is built by bending the copper tube into multi U-turns in the evaporator and condenser zones, the straight tubes in the adiabatic zone are made of borosilicate glass for aiding flow visualization. The internal and external diameters of the copper tube were chosen to be 2 mm and 3 mm, respectively. Eight K-type thermocouples were used to monitor the temperature in the evaporator and condenser. The evaporator is exposed to heat flux by means of mica heater with a capacity of 60W and the input voltage and current were measured by the digital multimeter. The condensation section was cooled by cooling water pumped from the cold bath.

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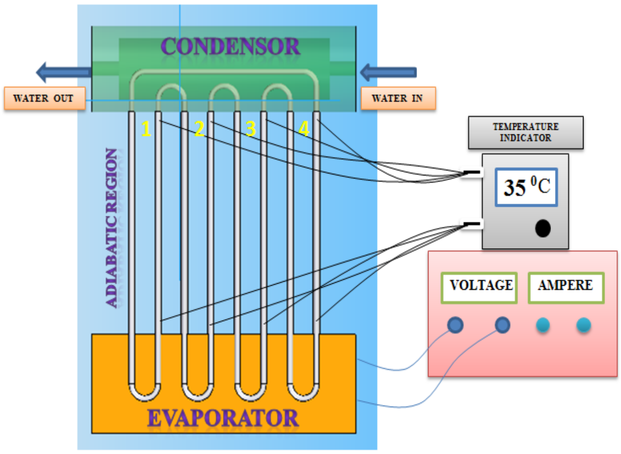
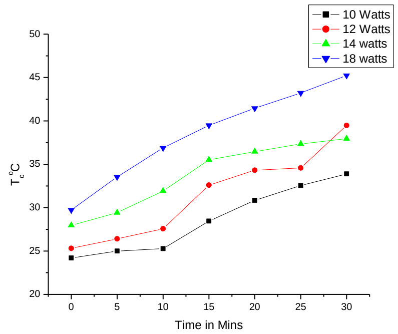


Fig.2. Experimental setup

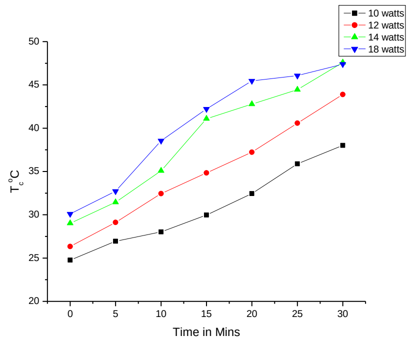
Acetone is used as working fluid at 50% filling ratio in vertical orientation. During the experiment, the heating power input was stepwise increased from a low value to relatively higher levels. The temperature data at the evaporator and condenser was recorded while reaching a quasi steady state. All tests were conducted at an ambient temperature of 25^0C.

3. RESULTS AND DISCUSSION

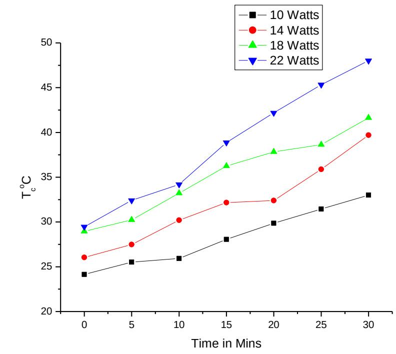
3.1Effect of Condenser temperature v/s time



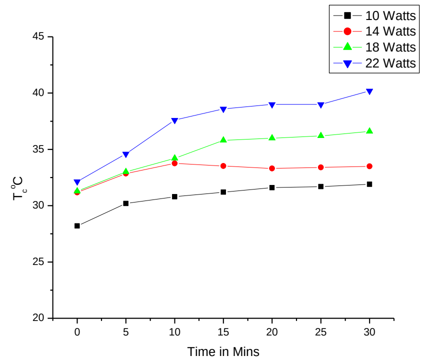
(a) Single turn



(b) Two turn



(c) Three turn



(d) Four turn

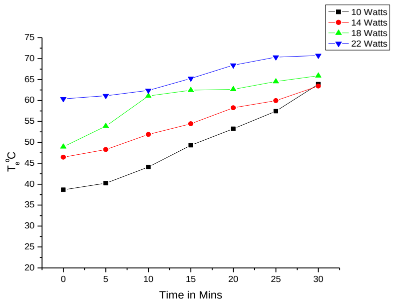
Fig.3.1 (a) to (d) shows the effect of condenser temperature v/s time for single, two, three and four turn PHP.

Figure 3.1(a) to (d) shows the variation of condenser wall temperature with respect to time for acetone as working fluid with different heat input in the PHP for single, two, three and four turns. The variation of condenser temperature with respect to time is less at lower heat input of 10 W compared to higher heat input of 22 W. This is because of very slow and intermittent motion of the working fluid at lower heat input. As the movement of the working fluid is slow at lower heat input due to lower energy levels, the hot fluid takes more time to reach the condenser section from the evaporator section. As more as the heat input more are the fluid fluctuations inside the PHP and hence more heat transfer rate. Thus the rise in the temperature of the cooling fluid is very less which results in lower variation of condenser temperature at lower heat load of 10W. But on the contrary, at a higher heat load of 22 W, even though the movement of the fluid is slow initially due to the inertia of the system, the movement is picked up after 15 min which results in the subsequent drop in the condenser temperature.

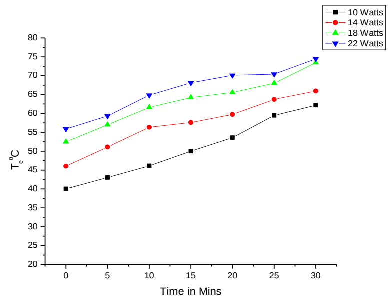
3.2 Effect of Evaporator temperature v/s time

Graphs 3.2(a) to (d) shows the variation of evaporator wall temperature with respect to time for acetone as working fluid with different heat input in the PHP for single, two, three and four turns. It is evident from the experiments that, there is a continuous pressure pulsation during the flow in a PHP. Thus the temperature readings are recorded only after the steady and continuous movement of the working fluid. The steady state evaporator temperature versus time-curve is almost linear. It is also clear that the fluctuations in the evaporator temperature are more at higher heat input of 22

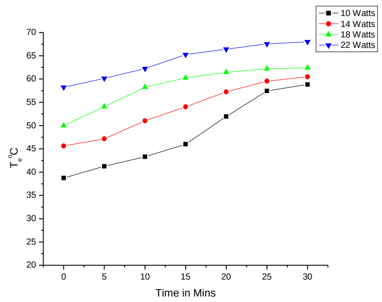
W due to intermittent motion of the working fluid and takes more time to reach the steady State. In high power heat input, the temperature of the evaporation section is high enough to keep the working fluid of high boiling points can boil vehemently and smoothly flow in one direction. Therefore, all the thermal resistances reduce smoothly and the differences between the number of turns are smaller with the increasing of heat input.



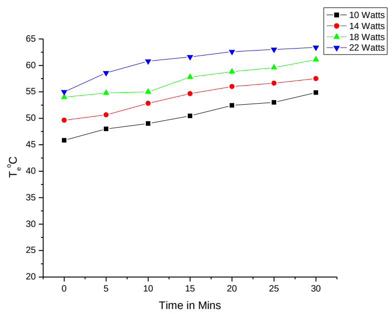
(a) Single turn



(b) Two turn



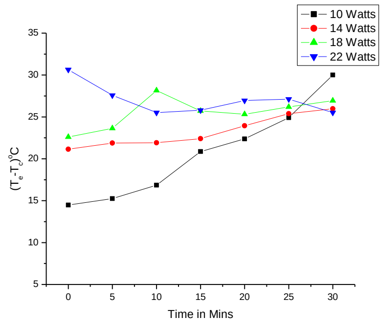
(c)Three turn



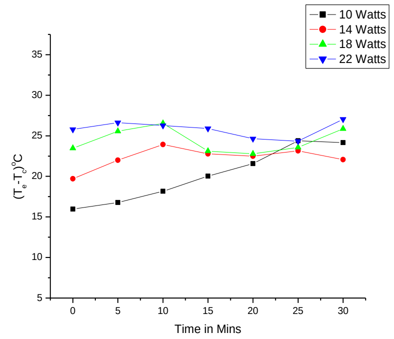
(d) Four turn

Fig.3.2 (a) to (d) shows the effect of Evaporator temperature v/s time for single, two, three and four turn PHP.

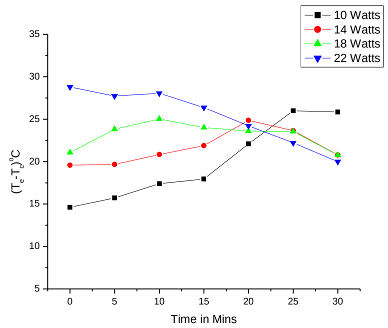
3.3 Temperature Difference between Evaporator and condenser v/s time



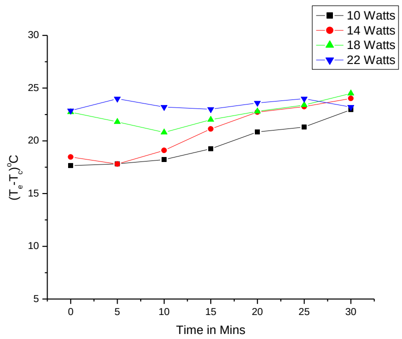
(a) Single turn



(b) Two turn



(c)Three turn



(d) Four turn

Fig.3.3 (a) to (d) shows the effect of temperature difference between Evaporator and Condenser v/s time for single, two, three and four turn PHP.

Fig.3.3 (a) to (d) shows the variation of temperature difference between evaporator and condenser with time at different heat inputs for Acetone at a fill ratio of 50%. It is observed from the figures that the temperature difference between evaporator and condenser is considerably less at lower heat input of 10 W. As the movement of the fluid is very slow at lower heat input which is associated with lot of fluctuations, the temperature difference between evaporator and condenser is higher at higher heat input. The vapour bubbles formation is regulating the pumping action in the PHP. If the bubbles higher in PHP, the heat transfer rate also higher from evaporator section to condenser section. The figures show that at four turn PHP give the lower temperature difference as compare to other turns. Therefore we can say that at four turn of PHP gives the higher heat transfer rate and lower thermal resistance.

3.4 Effect of Thermal resistance v/s heat input for Single, Two, Three and Four Turn PHP

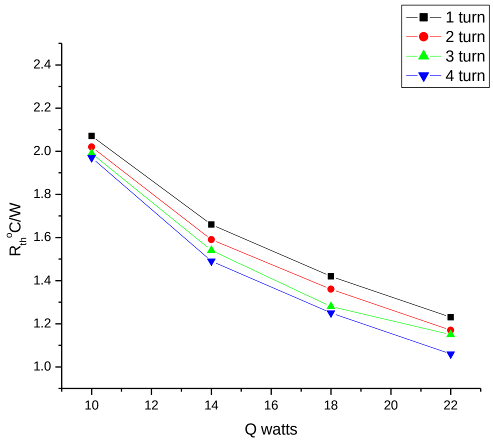


Fig.3.4.Thermal resistance v/s heat input

Fig.3.4 shows the variation of thermal resistance with heat input for single, two, three and four turns. From the figure it is clear that the thermal resistance decreases with increase in heat input for all the turns considered. 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. It indicates how much resistance does heat experiences in the system; so that the condenser region temperature cannot rise very high, and the system thus seems to be effective in cooling purpose. 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. thermal resistance has an inverse relationship with heat input. The Acetone with 50% filling ratio with four turn exhibit lower values of thermal resistance compared to other turns. This shows that four turn PHP was most suitable for PHP operation.

4. CONCLUSION

An experimental investigation on thermal analysis of a Closed Loop Pulsating Heat Pipe was conducted for multi turns at constant filling ratio with different heat inputs. The conclusions that could be drawn from this investigation are as follows:

- Generally, Thermal Resistance is reduced as a result of increasing heat input power.
- Lowest value of thermal resistance is obtained for four turn PHP.
- It could be also observed that PHP has better operational performance and self- sustained thermally driven pulsating action for charging ratio of 50% for Acetone in vertical position for four turns.

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