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EFFECT OF WORKING FLUID AND FILLING RATIO ON PERFORMANCE OF A CLOSED LOOP PULSATING HEAT PIPE

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Abstract

This paper presents preliminary experimental results on thermal performance of a closed loop pulsating heat pipe (CLPHP) using copper tube having internal and external diameter with 2 mm and 3 mm respectively. For the experimentation, filling ratio (FR) was varied from 30 % to 70% with 10% increments, four turns and different heat inputs of 10 to 22 W(Watts) is supplied to PHP's. The position of the PHP's was vertical bottom heat mode. The length of evaporator, adiabatic and condenser section was maintained 55, 80, and 50 mm respectively. The working fluids are selected as Acetone, Methanol, Ethanol, CCL_4 (Carbon Tetrachloride), and Benzene. In this study, characteristics of the thermal resistance and average evaporator temperatures at different heat input for various working fluids have been determined. The result shows that, the thermal resistance decreases rapidly with the increase of the heating input from 10 to 22 W. Further, slowly was extended on different working fluids as mentioned. From the experimental results, Acetone was found to be better working fluid as compared to other fluids.

Keywords: Pulsating heat pipes, Methanol, Acetone, and Benzene.

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

Nomenclatures

CCL_4	Carbon Tetrachloride
CLPHP	Closed loop pulsating heat pipe
FR	Filling ratio
I	Current
Q	Heat input
R_{th}	Thermal resistance
U	Input voltage

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 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 (between 1 and 3 mm), usually made of copper, bent with 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 bubble. 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. The important feature of the heat pipes is its ability to transport a large amount of heat over its length with a small temperature drop.

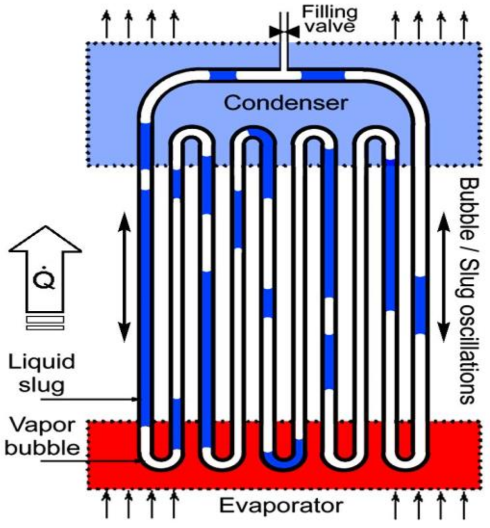


Fig. 1. Schematic representation of pulsating heat pipe.

The huge heat transportation in heat pipe is accomplished by liquid evaporation at heat source followed by condensation at the heat sink side, and finally the condensate liquid moves back to evaporator via wick structures using capillary force [4]. One of the outstanding features of PHP is its long distance transporting ability. The heat transfer of PHP occurs due to self exciting oscillation which may be driven by fast fluctuating pressure wave engendered from nucleate boiling and subsequent condensation of the working fluid [5]. One of the outstanding features of PHP is its long distance transporting ability. The heat transfer of PHP occurs due to self exciting oscillation which may be driven by fast fluctuating pressure wave engendered from nucleate boiling and subsequent condensation of the working fluid [6].The PHP has no internal wick structure and is easier to manufacture with fewer operating limitations [7].

Savino et al. [8] suggested that the use of binary and ternary mixtures of water and alcohols may improve the performance of the "wickless heat pipe". This work explores the thermal performance of a PHP working with an azeotropic mixture of water (4.5% wt.) and ethanol (95.5% wt.) in comparison to pure Ethanol. It was found that the wall surface condition, evaporation in the heating section, superheat, bubble growth, and vapor bubbles trapped in cavities at the capillary inner wall affect the start-up of oscillating motion in the pulsating heat pipe. A vertical, closed loop, copper PHP with Ethanol as the working fluid is first experimentally investigated by Sameer Khandekar et al. [9]. 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. [10], 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. [11].

2. Description of the Experiment set up

The PHP's is built by bending the copper tube into four 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 lengths of the evaporator, adiabatic and condenser section are 55 mm, 80 mm, and 50 mm, respectively as shown in Fig. 2. 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; four were employed in the evaporator (namely T_{e1}, T_{e2}, T_{e3} and T_{e4}), while the rest were used in the condenser (termed as T_{c1}, T_{c2}, T_{c3} and T_{c4}). The evaporator is exposed to heat flux by means of mica heater with a capacity of 60W and the input voltage (U) and current(I) were measured by the digital multimeter. The condensation section (i.e., condenser) was cooled by cooling water pumped from the cold bath. Both the evaporation and adiabatic sections were well thermally insulated to minimize the heat loss from these two sections to the ambience.

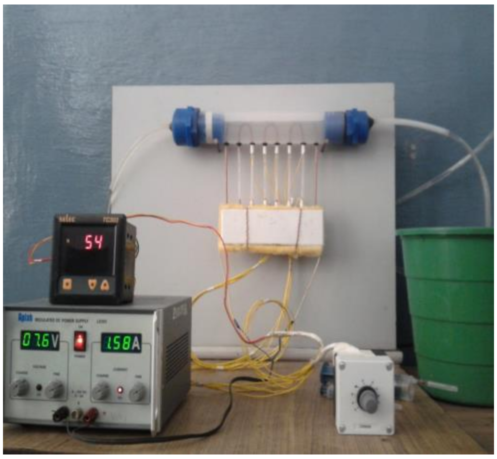


Fig. 2. Experimental setup.

Five working fluids such as Acetone, Methanol, Ethanol, CCL_4 (Carbon Tetrachloride), and Benzene were used, at different filling ratios from 30% to 70%. 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.

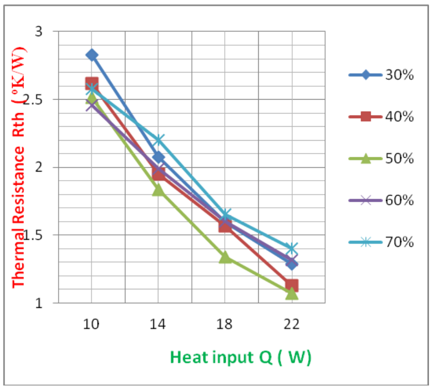
3. Results and Discussion

In the following, the effects of working fluid and filling ratio on the thermal performance of CLPHP's at different heating power inputs will be discussed.

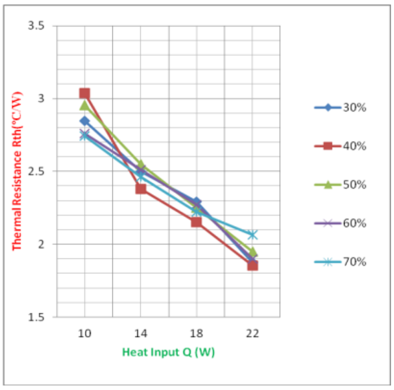
3.1. Effect of heat input on thermal performance of PHP

The data recorded on Thermal resistance versus Heat input for the different working fluids used in the study are presented in Fig. 3(a) to (e). Figures show the effect of heat input on the thermal resistance which is defined as the ratio of the temperature difference between the evaporator and the condenser to the net heat input in the system. It is clear that the thermal resistance decreases with increase in heat input for all the working fluids considered. Till about 18W input power the thermal performance improvement is quite drastic while thereafter it is mild. In general, the heat input is the 'pump' for the thermo-fluidic action.

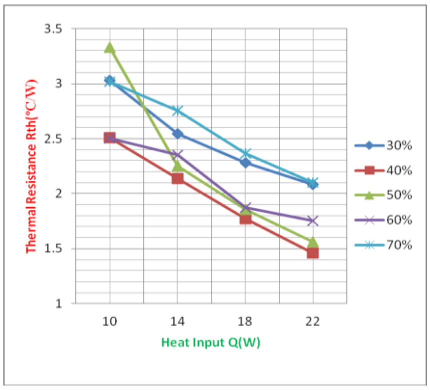
Thus, increasing pumping power increases the performance. Further, it is seen that Acetone exhibits lower values of thermal resistance compared to other working fluids. This is due to lower temperature difference between evaporator and condenser sections. The lower values of thermal resistance of Acetone indicate that Acetone has better heat transport capability compared to other working fluids.



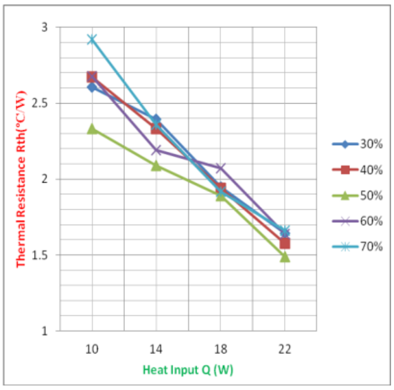
(a) Acetone.



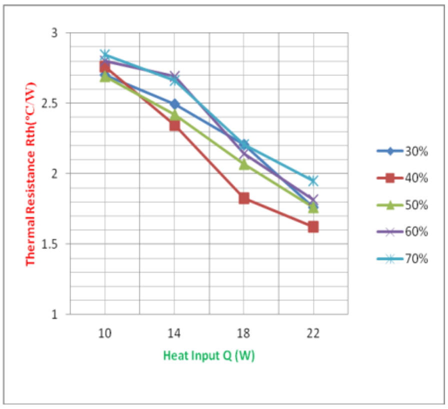
(b) Benzene.



(c) CCL_4.



(d) Methanol.

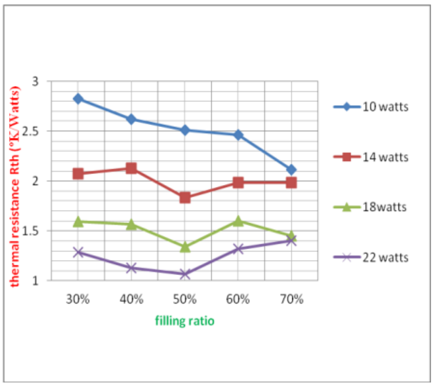


(e) Ethanol.

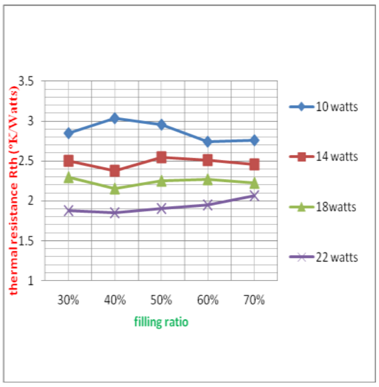
Fig. 3. (a) to (e) The effect of heat input on thermal resistance of pulsating heat pipe.

3.2. Effect of charging ratio on thermal resistance of pulsating heat pipe

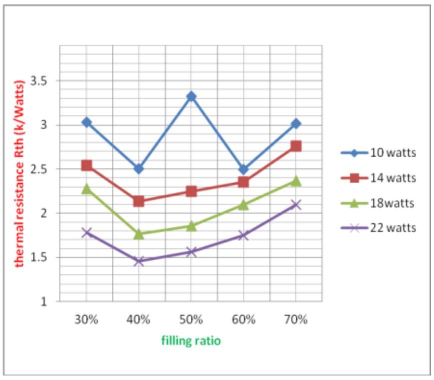
The data recorded on Thermal resistance versus filling ratios of working fluids for the different heat inputs on the thermal performance of PHP are presented in Fig. 4(a) to (e). The overall thermal resistance of the PHP firstly reduces with the increase of the amount of heat input, but rises when the heat input exceeds the heat transfer limit. The overall thermal resistance of the PHP firstly reduces with the increase of the amount of heat input, but rises when the heat input exceeds the heat transfer limit.



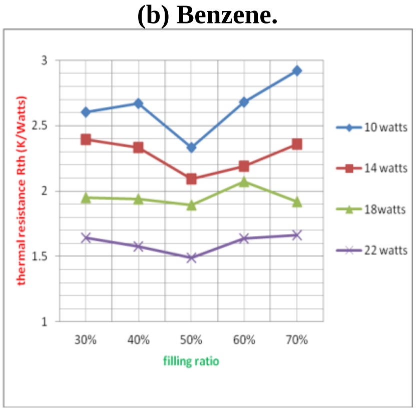
(a) Acetone.



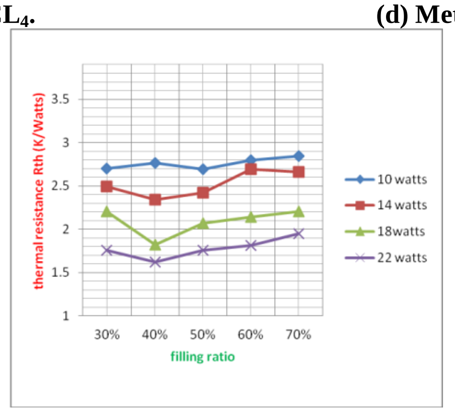
(b) Benzene.



(c) CCL_4.



(d) Methanol.



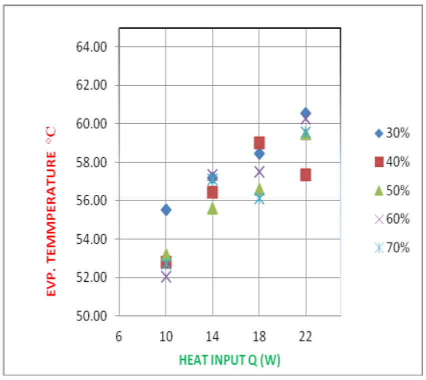
(e) Ethanol.

Fig. 4. (a) to (e) The effect of charging ratio on thermal resistance of pulsating heat pipe

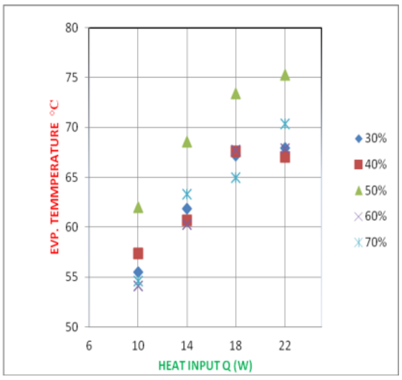
While charging 30%, 40%, 50%, 60%, and 70% the heat pipe works in the PHP mode with a steady and continuous flow, more liquid can return to the heating section so that the heat transfer limit is apparently increased. In addition, the frictional resistance increases with the increase of charging ratio so that the return of the liquid becomes difficult. As a result, there is an optimal charging ratio (50%) for which the thermal resistance has a lowest value of 1.051 K/W at the heating power of 22W for Acetone , an optimal charging ratio (40%) for which the thermal resistance has a lowest value of 1.855 K/W at a heating power of 22W for Benzene, an optimal charging ratio (40%) for which the thermal resistance has a lowest value of 1.46 K/W at a heating power of 22W for CCL4, an optimal charging ratio (40%) for which the thermal resistance has a lowest value of 1.489 K/W at a heating power of 22W for Methanol and an optimal charging ratio (50%) for with the thermal resistance has the lowest value of 1.63 K/W at a heating power of 22W for Ethanol, with the heat transfer limit reaches the highest.

3.3. Effect of evaporator temperature on thermal performance of PHP

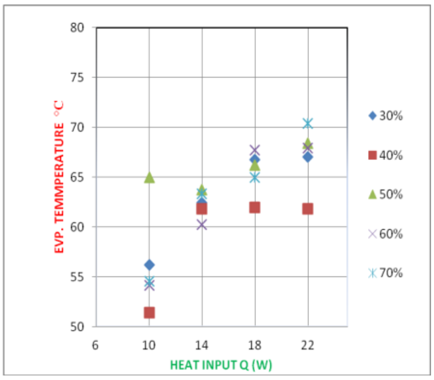
The effect of Heat input on Evaporator temperature when Acetone, Benzene, CCL_4, Methanol and Ethanol used as working fluids in PHP shown in Fig. 5(a) to (e). From this comparison, it is possible to conclude that evaporator section temperature for all working fluids for higher heat loads; acetone could be stated as the best working fluid to be used as it presents the lowest evaporator section temperatures. It is interesting to point out that the working fluid selection is an important parameter to select the tube inner diameter in order to have the slug/plug pumping action. This parameter is also important when evaluating the best thermal behavior for a specific PHP related to the evaporator section temperature. Thus, the working fluid selection is a very important variable that should be carefully considered as a design parameter, which could lead to a worse or better thermal performance of the PHP.



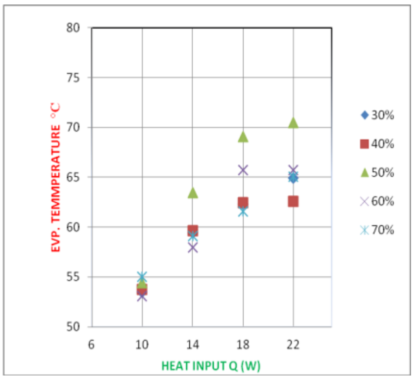
(a) Acetone.



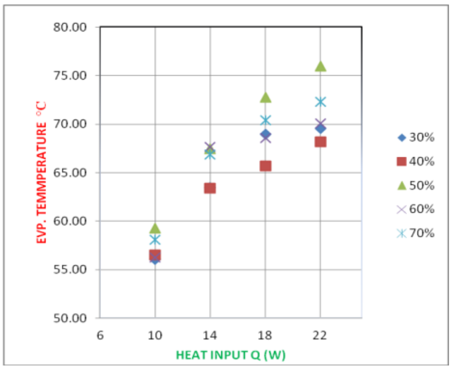
(b) Benzene.



(c) CCL_4.



(d) Methanol.



(e) Ethanol.

Fig. 5. (a) to (e) The effect of heat input on evaporator temperature for different charging ratio.

4. Conclusion

An experimental investigation on thermal analysis of a Closed Loop Pulsating Heat Pipe was conducted for five different working fluid and different filling ratios 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.
- With all working fluids, Acetone is having lower value of thermal resistance compared with other working fluids hence Acetone is most suitable working fluid for PHP's operation.
- It is observed that PHP has better operational thermal performance and self-sustained thermally driven pulsating action for charging ratio of 50% for Acetone and methanol, 40% for Benzene, CCL_4 and Ethanol in vertical position with working fluids.
- Device acts as true PHP's only in the range of 40 to 50% filling ratio.

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References

1. Akachi, H. (1993). Structure of a heat pipe. US Patent No. 5219020.
2. Thompson, S.M.; Ma, H.B.; and Wilson, C. (2011). Investigation of a flat-plate oscillating heat pipe with Tesla-type check valves. *Experimental Thermal and Fluid Science*, 35 (7), 1265–1273.
3. Yang, H.; Khandekar, S.; and Groll, M. (2009). Performance characteristics of pulsating heat pipes as integral thermal spreaders. *International Journal of Thermal Science*, 48 (4), 815–824.
4. Vasiliev, L.L. (2005). Heat pipes in modern heat exchangers. *Applied Thermal Engineering*, 25 (1), 1–19.
5. Rittidech, S.; Terdtoon, P.; Murakami, M.; and Kamonpet, P. (2003). Correlation to predict heat transfer characteristics of a closed-end oscillating heat pipe at normal operating condition. *Applied Thermal Engineering*, 23 (4), 497–510.
6. Thompson, S.M.; Ma, H.B.; and Wilson, C. (2011). Investigation of a flat-plate oscillating heat pipe with Tesla-type check valves. *Experimental Thermal and Fluid Science*, 35 (7), 1265–1273.
7. Zhang, J.L.; and Faghri. (2008). Operating Characteristic Investigations in Pulsating Heat Pipe. *Journal of Heat Transfer*, 128, 1329-1334.
8. Savino, R.; Cerere, A.; and Di Paola, R. (2009). Surface Tension Driven Flow in Wickless Heat Pipes with Self-rewetting Fluids. *International Journal of Heat and Fluid Flow*, 30, 380-388.
9. Sameer Khandekar.; Xiaoyu Cui.; and Manfred Groll. (2002). Thermal performance modeling of pulsating heat pipes by artificial neutral network. *Proceedings of 12th International Heat Pipe Conference*. Moscow, Russia, 215-219.
10. Guoping.; and Vogel, M. (2006). Thermal characterization of pulsating heat pipes, *Anbar Journal for Engineering Sciences*. 551 – 556.
11. Akyurt, M.; Lamfon, N.J.; Najjar, Y.S.H.; and Habeebullah, M.H. (2009). Modeling of waste heat recovery by looped water-in-steel heat pipes. *International Journal of Heat and Fluid Flow*, 263-271.