

EXPERIMENTAL INVESTIGATION OF AN OPEN LOOP CLOSED END PULSATING HEAT PIPE

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ABSTRACT

This paper presents an experimental study of an open loop pulsating heat pipe (OLPHP) of 0.9 mm inner diameter. The performance characterization has been done for two working fluids at vertical and horizontal orientations. Water and Acetone are employed as the working fluid with 50% fill ratio. The experimental results indicate a strong influence of gravity and thermo physical properties of the working fluids on the performance of OLPHP. Regarding the working fluids, Water has performed better in both vertical and horizontal orientation as lower evaporation temperature has been achieved at all heat loads. Both working fluids perform better at horizontal orientation. OLPHP of 0.9 mm ID in this experiment shows better thermal performance as compared with experimental results of Roger R. Reihl [1] performed with OLPHP of 1.5 mm ID.

Keywords: Pulsating Heat Pipe, Inclination Angles, Pulsating Action, Diametrical Effect

1. INTRODUCTION

Nowadays the demand of increased capacity of heat transfer devices has risen drastically. One possible solution for power electronics applications is the use of liquid-vapor phase change cooling devices such as the heat pipes. Although the conventional heat pipes (e.g. mini or micro) are one of the proven technologies, the manufacturing of the complex, miniaturized wick structure/geometry of these heat pipes could become the most cost intensive factor. Another common limitation is the capillary limit, which occurs when the wick structure cannot return an adequate amount of liquid back to the evaporator. To overcome these difficulties researchers have come up with pulsating heat pipes (PHPs) which work on principle of oscillation of the working fluid and phase change phenomenon in a capillary tube. PHP is a meandering tube of capillary dimensions with many turns filled partially with a suitable working fluid with no wick structure. PHPs are passive two-phase thermal control devices first introduced by Akachi et al [2]. In this application, reduced diameter channels are used, which are directly influenced by the selected working fluid. The vapor plugs generated by the evaporation of the working fluid push the liquid slugs toward the condensation section and this motion causes flow oscillations that guide the device operation [3].

There are two possible configurations for PHPs, being as an open loop and as a closed loop. In the open loop configuration, one end of the tube is pinched off and welded, while the other end may present a service valve for evacuation and charging. The closed loop configuration has both ends connected and the fluid is

allowed to circulate. On the open loop configuration, the liquid circulation is not possible. In this case, it is believed that a counter-current liquid/vapor flow occurs in order to promote the proper device operation [4]. Therefore, better understanding on this behavior is still a motivation for further investigations. The purposes of this investigation are to study the heat transfer characteristics of an OLPHP and evaluate several issues related to its performance.

2. EXPERIMENTAL PROCEDURE

The device used during the experimental tests is shown in Figure 1. A pulsating heat pipe configured as an open loop is built using a capillary copper tubing with 2.30 mm OD, 0.90 mm ID, 4.9 m long to form 13 parallel channels with 12 curves. The apparatus is placed on a support that allowed its adjustment on vertical and horizontal orientations.

The OLPHP as shown in the figure 1 is built with 3 regions: evaporation, adiabatic and condensation, each one is 300 mm wide. The evaporator section is 105mm long, the adiabatic section is 100 mm long and condenser is 95 mm long with filling ratio of 50%. For the tests under vertical orientation, the evaporation section is always below the condensation section. For the tests under horizontal orientation, all sections are at the same plane. Both evaporation and adiabatic sections are thermally insulated, while the condensation section is open to the surrounding air. The condensation section is cooled by forced air, using a fan able to deliver air at a

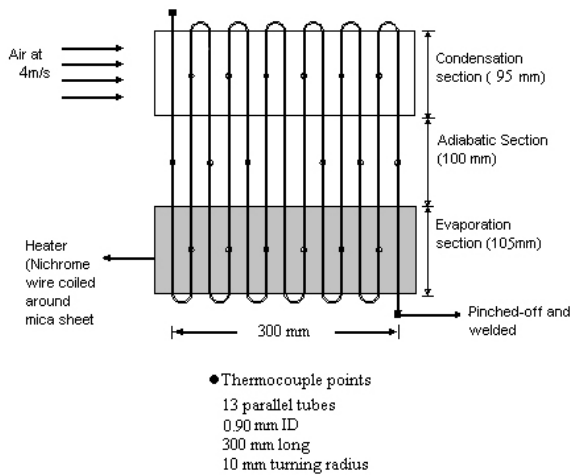


Fig 1. Cross Section of the OLPHP Test Apparatus

velocity of 4 m/s. The evaporation section is in contact with Ni-Cr wire which is coiled around two mica sheets to deliver the desired heat load. The heat loads are administered by an AC power supply. Eighteen K-type thermocouples are used to monitor the device performance during the tests. A total of 6 thermocouples are located at each section. The thermocouples are connected to a digital temperature controller (0°C to 800°C) to monitor wall temperatures. The temperatures are recorded at every 5 minutes. All experimental tests are performed on a heat load profile basis, where the perspective is to evaluate the behavior of OLPHP related to the orientation and applied power.

3. RESULTS AND DISCUSSION

3.1 Temperature Profile

When testing the OLPHP with Acetone at vertical orientation as shown in Figure 2(a), it is observed that a more intensive plug/slug pumping action is initiated at 15W. For this working fluid, OLPHP presents even temperature distribution along the evaporation, adiabatic and condensation sections. At horizontal orientation as shown in Figure 2(b) Acetone exhibits more drastic pulsations and intensive oscillations start from 15W. Considering that the channels are of capillary dimension at horizontal orientation, the surface tension and shear stress effects are very expressive.

For Water at vertical orientation as shown in Figure 3(a) oscillations begin from 20W. At the highest heat load of 45W the evaporation section temperature rises to 110°C. So Water is more suitable at lower heat loads than 45W. But at all other heat loads the evaporation section temperature of Water is lower as compared to Acetone. At horizontal orientation as shown in Figure 3(b) temperature distribution of Water is more uniform as compared to vertical orientation. OLPHP does not present an indication of pulsations during its operation at low heat loads, even though some oscillations have been continuously captured and have become more evident after 30W.

From comparison of evaporation section temperature

profile of Acetone it is found that at all heat load levels the evaporator temperature has been considerably lower at horizontal orientation. From comparison between orientations of Water it is observed for low heat loads up to 25W, evaporator temperature is much lower at horizontal orientation and performance is better. At higher heat loads there have been fluctuations and performance is similar or slightly better in horizontal orientation. From comparison of temperature profiles of both working fluids at vertical orientation it is observed that Acetone exhibits the higher evaporation temperature and Water has lower evaporation section temperature at all heat loads. Hence, Water is the better choice for use at vertical orientation. For all heat loads both working fluids show almost similar evaporation temperature with little fluctuations at horizontal orientation.

3.2 Thermal Conductance

Thermal conductance of the heat pipe is calculated by using the evaporation and condensation section temperature.

$$G_{calc} = \frac{Q}{(T_E - T_C)} \quad (1)$$

Figure 4 denotes the comparison of thermal conductance of OLPHP at various orientations using different working fluids. It is observed from the figure 6 that for Acetone at vertical orientation the thermal conductance doesn't change much with heat load. At horizontal orientation thermal conductance of Acetone gradually increases. At 30W heat load there is a sudden drop which could be considered as an anomaly. Water doesn't show any definite trend but mostly the performance is better at horizontal orientation. Water has the higher thermal conductance at almost all heat loads as compared to Acetone. So it is concluded that with regard to thermal conductance Water performs better than Acetone.

3.3 Overall Efficiency

The overall efficiency is determined by the ratio of the thermal conductance of copper tube with working fluids (G_{calc}) and empty copper tube (G_{ref}).

$$\eta = \frac{G_{calc}}{G_{ref}} \quad (2)$$

Figure 5 indicates the variations of overall efficiency of OLPHP using different working fluids at various orientations. It is observed from the figure 5 that Water has the higher efficiency for both the orientations so it is better than Acetone.

3.4 Diametrical Effect

The findings of this experiment have been compared with the experimental results of Roger R. Reihl [1]. Roger R. Reihl conducted the same experiment with copper tube of 1.5 mm inner diameter. The 0.9mm inner diameter copper tube in this experiment has operated successfully and shown good thermal performance for both the orientations compared with the copper tube of 1.5 mm inner diameter.

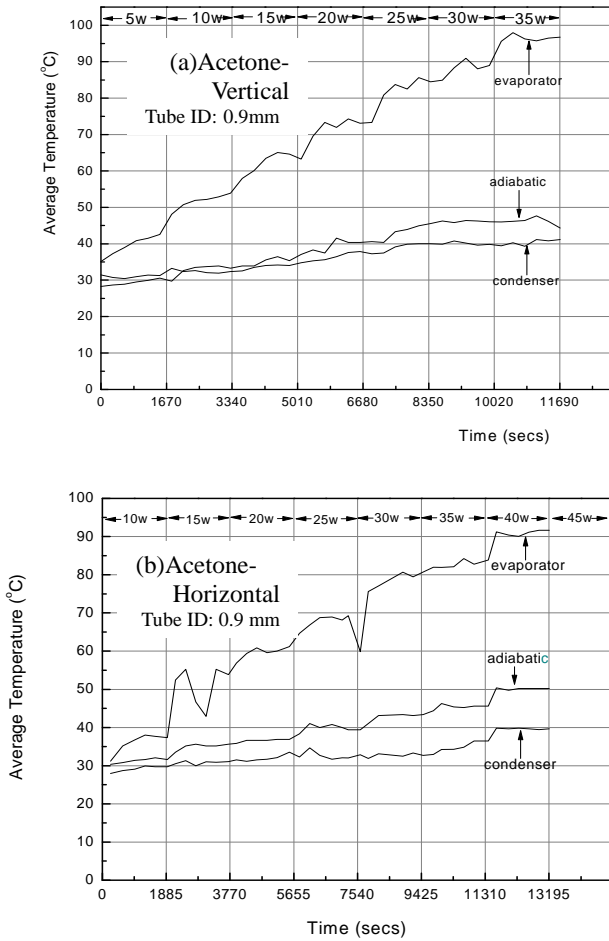


Fig 2. Temperature Profile along the length of OLPHP for Acetone

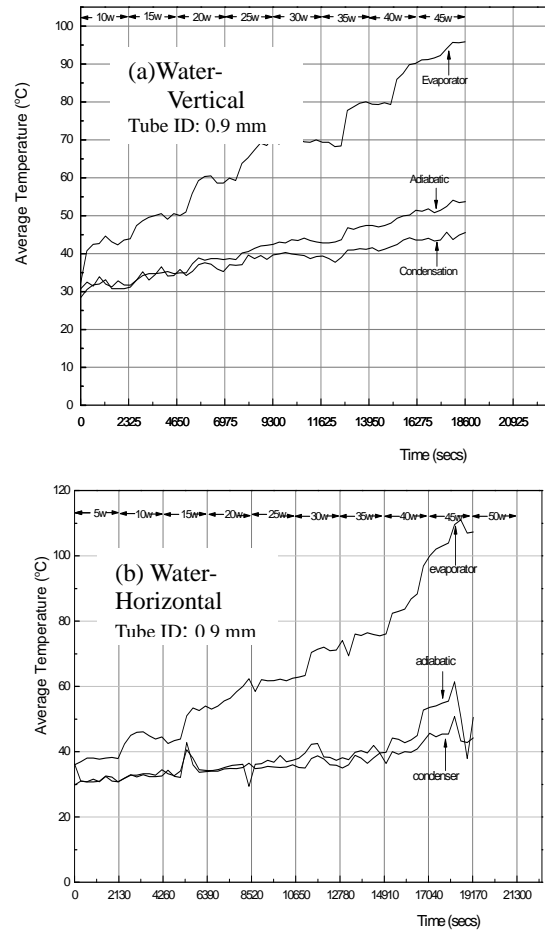


Fig 3. Temperature Profile along the length of OLPHP for Water

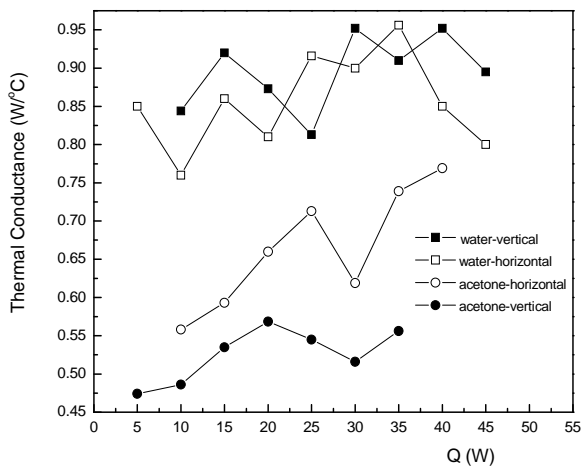


Fig 4. Comparison of Thermal Conductance

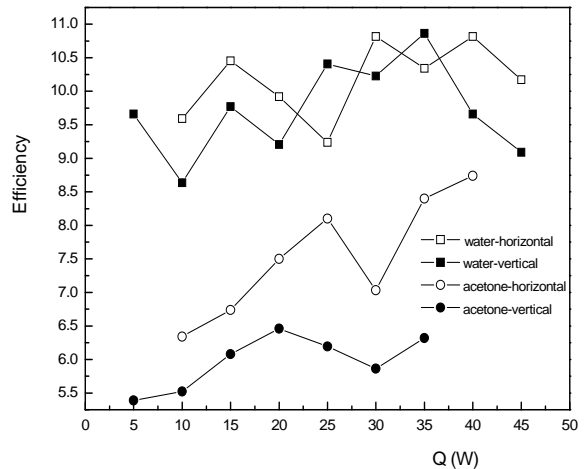


Fig 5. Comparison of Overall Efficiency

Figure 6 signifies the effect of diameter on the performance of OLPHP for different working fluids. For Water, as shown in figure 6(a), the 0.9mm inner diameter

copper tube has operated successfully and shown good thermal performance for both the orientations. In case of Acetone, as shown in figure 6(b), the same result is

obtained again but only for the vertical orientation. For horizontal orientation the 1.5 mm inner diameter copper tube showed better thermal performance.

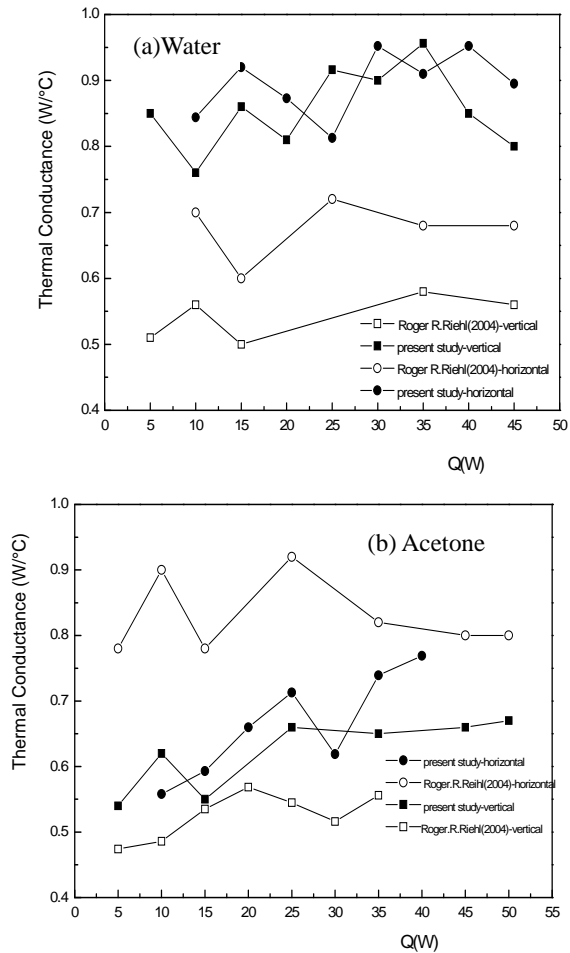


Fig 6. Diametrical effect

4. CONCLUSION

For both the orientations Water shows better thermal performance than Acetone. So Water can be regarded as the better working fluid. Acetone shows drastic pulsations at all heat loads for both the orientations. The plug and slug pumping action started from the very beginning of 5W of power level. In case of Water, for horizontal orientations pulsation started at the very beginning and continued through out all heat loads but for vertical orientation, pulsation did not start till 25W of power level.

The smaller 0.9 mm ID heat pipe shows better thermal performance compared with 1.5 mm ID heat pipe.

5. REFERENCES

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6. NOMENCLATURE

Symbol	Meaning	Unit
G	Thermal Conductance	W/°C
T _C	Average Condenser Temperature	°C
T _E	Average Evaporator Temperature	°C
Q	Heat Load	W

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