International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2013): 4.438

Experimental Analysis on Effect of Design Parameters on the Performance of Single Loop Pulsating Heat Pipe

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Abstract: ***The increasing the demand of electronics cooling in the field of science, the novel technologies available with us to reduce such type of load on the devices. The pulsating heat pipe (PHP) is one of theadvance technologies in electronic cooling application compared to conventional heat pipe. In this experimentation, the performance of single loop pulsating heat pipe was fabricated and tested. The tube of copper material having internal diameter is 2 mm and outer diameter is 3 mm. The PHP was performed on different filling ratio 60% to 80% in steps of 10% and heat input was supplied from 8 W to 16 W in steps of 2 W. The working fluid was used as Acetone and Heptane. The main aim of this experiment is analysis on effect of working fluid and filling ratio on design parameters of single loop pulsating heat pipe and to find out the suitable working fluid for best filling ratio for different heat inputs.The thermal resistance and heat transfer coefficient was evaluated at different filling ratio. The acetone gives the best performance at 60% filling ratio at given heat input as compared to heptane.***

Keywords: Pulsating Heat Pipe (PHP), single loop, working fluid and filling ratio

1. Introduction

All electronic components, from microprocessors to high power generators, generate heat and rejection of this heat is necessary for their optimum and reliable operation. Presently the chip flux ranges between 40 to 120W/cm^{2}and in next few coming decades it is expected to increase up to 200 W/cm^2. To reduce such type of load on these device there are novel technologies available which is in small size and shape electronic devices, because they are compact in nature and more efficient, due to this it has less area for cooling system, to manage these type of problem i.e. thermal management of microelectronic devices there is a requirement of miniaturization of two phase passive heat transfer device. A Pulsating heat pipe (PHP) is typically suited for microelectronics cooling consists of a plain capillary tube of small dimensions with number of U turns. The heat pipe is first evacuated and then filled partially with a required filling ratio working fluid. If the diameter of the pulsating heat pipe is very small, the fluid distributes itself into an arrangement of liquid slugs separated by vapor bubbles and moves into the capillary tube due to pressure gradient.

The pulsating heat pipe proposed and presented by Akachi. H. in 1990[1], is a new member of the wickless heat pipe. Due to its excellent features, such as high thermal conductivity, high thermal performance, small in size, simple design and low cost, the PHP is a novel technology in electronics application, like heat exchanger, thermal management control system, and spacecraft thermal control system.

There are various design parameters which affect the thermal performance of PHP, like tube diameter and material, orientation of PHP, number of turns, design of evaporator and condenser section and tilt angle. Khandekar [2], studied that a large hydraulic diameter, results in lower thermal resistance and increase the effective thermal conductivity. The best thermal performance of pulsating heat pipe is obtained, when the PHP operate in vertical bottom orientation [3]. If the number of turns of PHP increases it provides flexibility to the PHP to operating at any orientation (i.e. at various angle of inclination). If the no. of turns is less then it operates in vertical position only [4]. Meena studied the effect of evaporator section length, when the evaporator length increase the critical heat transfer decreases. The latent heat of vaporization affects the critical heat flux [5]. The thermal performance of PHP also depends on how the PHP is located. In horizontal position no gravity affects the PHP, but when angle changes the gravity start playing its role in the capillary tube [6].H. Yang et al. [7] present an experimental study on the operational limitation of closed loop pulsating heat pipes. The three operational orientations were investigated, i.e. horizontal heated, vertical bottom heated and vertical top heated orientations. The results show that the best performance was obtained in the vertical orientation with bottom heating for the CLPHP with 2 mm ID tubes.While for the CLPHP with 1 mm ID tubes, orientation played almost no role. A 50% filling ratio was optimum for both CLPHPs to obtain best performances in all the orientations. M. Mameli et al. [8] experimentally studied the wide range of pulsating heat pipe and then partially filled with working fluid. Important parameters i.e. local fluid and wall temperatures and corresponding internal pressure fluctuations have been recorded and visualized the internal two phase flow patterns.The heat transfer coefficient in the evaporator zone has been estimated at different heat inputs of related flow patterns.Pachghare et al. [9] used the pure and binary working fluid CLPHP and concluded that no measurable difference has been recorded between the pure and binary working fluid. Working fluid behavior is strongly depends on thermo- physical properties, but latent heat of vaporization is main property that strongly affects the thermal performance of PHP [10]. There are some results of single loop Pulsating Heat Pipe are described in miniature literature [11, 12].

From above literature, it is clear that at different situations, different working fluids have their benefits in PHP. Very few literatures are available on single loop pulsating heat pipe. Many experimental investigations carried out on more than one loop using different types of working fluid. No more data available on single loop PHP. In the present work, experiment was carried out on effect of design parameters on single loop PHP using Acetone and Heptane as working fluids for different heat inputs.

2. Experimentation

The Experiment was carried out on single loop pulsating heat pipe using Acetone and Heptane as working fluids for different filling ratio at different heat inputs.

Table1: Thermo physical properties of working fluids

Working fluids	Boiling Point Ts (^{0}C)	Liquid density ρ_l Kg/m^3 (20^{0}C)	Vapor density ρ_v Kg/m^3 (20^{0}C)	Liquid specific heat Cp_l (KJ/Kg ^{0}C) (20^{0}C)	Surface tension σx10^3 N/m(20^{0}C)
Acetone	56.2	792	2	2.35	23.7
Heptane	98.43	684	3.5	2.24	19.3

2.1 Experimental Setup

Figure 1 illustrates that, the schematic of single loop pulsating heat pipe. The experimental setup consists of cold bath unit, evaporator flat heater and control panel for measurement of temperature.

A CLPHP mainly divided into three sections;

- The evaporator section: it is act as heating section, which received the heat from flat heater which is connected to the control panel
- The adiabatic section: It is acts as insulating section; there is no heat transfer from adiabatic zone to the surrounding.
- The condenser section: it is act as cooling section, which released the heat to the cooling water which is obtained from the cold bath unit.

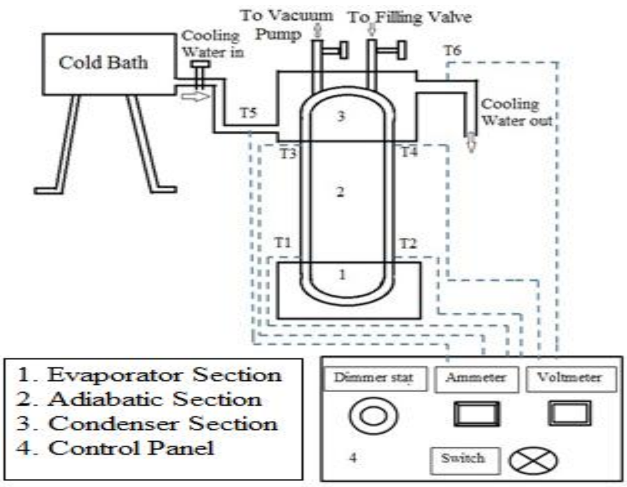

Figure 1: Schematic of Experimental Setup

A closed loop pulsating heat pipe was tested and fabricated for investigating the performance of design parameters on single loop PHP. The PHP design consists of 2mm inner diameter and 3mm outer diameter of copper tube as material. The length of evaporator section (Le = 170 mm), length of condenser section (Lc = 150 mm) and length of adiabatic section (La = 130). The Centre distance between two tubes (i.e. pitch) was maintained 60 mm. Acetone and Heptane was used as working fluid. The orientation of PHP was vertical and the vertical bottom heating was applied to the evaporator section. At the top of the capillary tube two T- valves are connected. One was for creating vacuum and second for filling the required amount of fluid (FR).The condenser section is cooled by a cooling box having dimensions of90×20×70 mm^3 which maintained flow rate of 30 ml/min.

Six K type thermocouples are used for temperature measurement at different points. The thermocouple can measured temperature up to 1260^{0}C. Two thermocouples are connected to evaporator section; two for condenser section and for inlet and outlet of the cooling water in and outlet through condenser section of wire diameter is 1 mm .All the six thermocouples are connected to the control panel for measurement of temperature at different points. The control panel consists of heat input in terms of electrical power supply through Dimmer stat (0- 1500 W). The Voltmeter (0-270 V) and Ammeter (0 - 4 A) was connected in line for the input power measurement. The flat heater of capacity 450W was used for heating the evaporator section and it is acts as heat source. The Filling Ratio was used 60% to 80% in steps of 20% for different heat input 8W to 16W in steps of 2W to analyze the thermal performance of PHP. The experiment was carried out for two working fluids viz, acetone and heptane. The syringe was used to inject the fluid into the heat pipe.

2.2 Experimental Procedure

Before conducting the experiment,it is confirmed that there is no fluid inside the tube. The required amount of working fluid is then filled through a syringe by opening the end of the non-return valve. The experiment setup shown in fig 1.The following procedure is adopted conducting the present transient steady state experiment;

- First create vacuum inside the Capillary tube by using a reciprocating vacuum pump.
- Then the device is filled with required Filling Ratio with the desired working fluid and closed the valve.
- Water was supplied from water tank to the condenser section.
- Flow rate was measured with beaker and stop watch.
- Power was supplied to the control panel from switch board.
- Control panel was connected to the PHP setup with the help of power cord, the flat heater was used for heating the oil bath starts heating. This is in turn heats the evaporator section.
- Provide a constant heat input to the heater up to steady state reached and temperature at different points of CLPHP are recorded on temperature indicator.
- After a steady state was reached, note down the readings for temperature at six different points. From these readings the thermal resistance and heat transfer coefficient will be

evaluated. Repeat the same procedure for the different working fluids at different heat inputs.

3. Data Reduction

The total thermal resistance is obtained from following equation;

$$R_{th} = \frac{\Delta T}{Q_{in}} = \frac{T_e - T_c}{Q_{in}} (^0C/W) \quad (1)$$

The convective heat transfer coefficient (h) of PHP is given by Rama Narasimha[10],

$$h = \frac{Q_{in}}{A_s \times (T_e - T_c)} W/m^2k \quad (2)$$

4. Results and Discussion

4.1 Effect of Heat input on Evaporator Temperature for Acetone and Heptane

Figure 4.1it is shows that the evaporator wall temperature is increases for both working fluids with increase of heat inputs at Fill Ratio 60%. It can be seen that the evaporator wall temperature at steady state is higher in case of Heptane and lower in the case of Acetone due to higher saturation temperature for Heptane. It is also observed that the system takes more time to reach the steady state in case of Heptane compared to Acetone. At higher inputs the maximum temperature obtained for heptane is 65^{0}C.

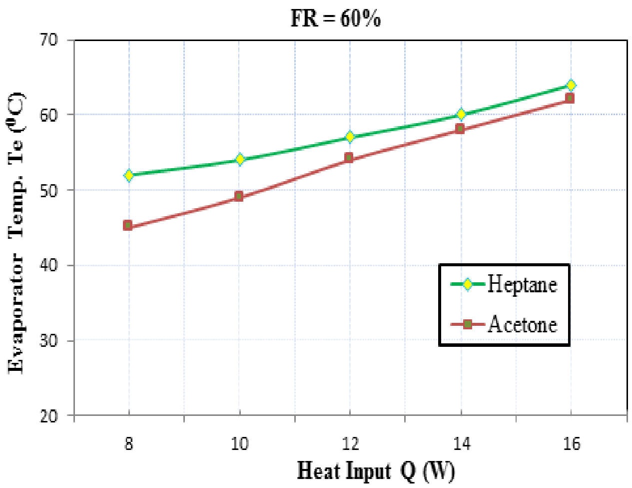

Figure 4.1: Plot of Heat input Vs Evaporator Temperature for Acetone and Heptane

4.2Effect of Fill Ratio on Temperature Difference for Acetone

Figure 4.2 shows the temperature difference between evaporator and condenser at steady state at different fill ratios for Acetone at a heat input power of 12 W. From the figure it is clear that the temperature difference between the evaporator and condenser is lower at a lower fill ratio of 60%, because at lower fill ratio, the saturation temperature is lower. At lower fill ratio the pressure difference between a vapor plug and liquid slug is decreases which results in reduction of saturation temperature.

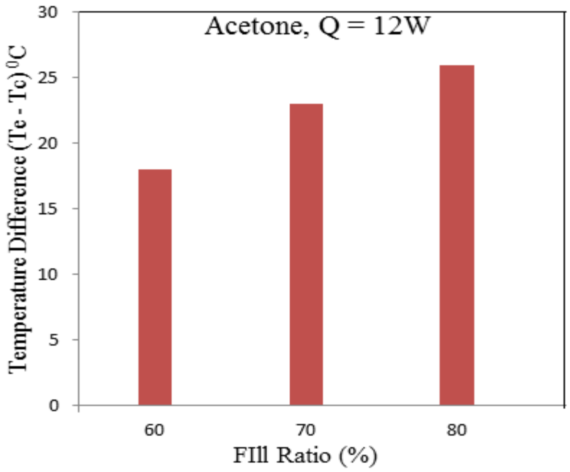

Figure 4.2: Temperature Difference plot for different Fill Ratio

4.3Effect of Fill Ratio on Thermal Resistance for Acetone

Figure.4.3it is seen that the thermal resistance is decreases with increase of heat inputs for all filling ratio at 60% fill ratio and Acetone as working fluid. At 60% fill ratio the thermal resistance is lower compared to other filling ratio, because the fluid circulation velocity is low.It isobserved that at lower fill ratio the temperature difference between evaporator and condenser is less compared to other filling ratio.

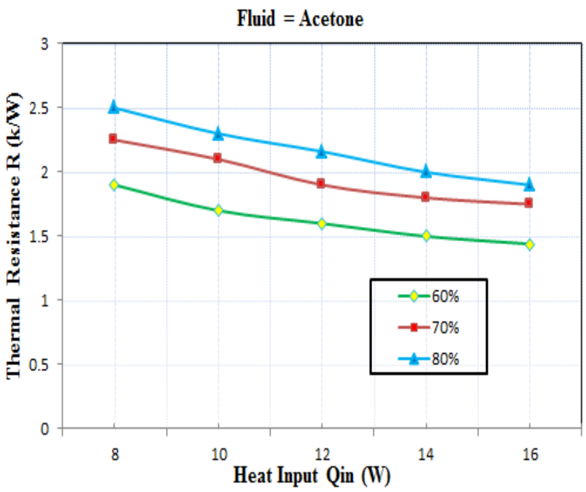

Figure 4.3: Typical Variation of Thermal Resistance with Heat Input Power at Different Fill Ratio for Acetone

4.4 Effect of Heat input on Thermal Resistance for Acetone and Heptane

Figure 4.4 shows the variation of thermal resistance with heat input for different working fluid at 70% fill ratio. From the figure it is clear that the thermal resistance decreases with increase in heat input for both the working fluid. As the temperature difference between evaporator and condenser is low for acetone, the thermal resistance is also very low. It shows that heat transfer capability of Acetone is more compared to heptane in same amount of heat transfer.

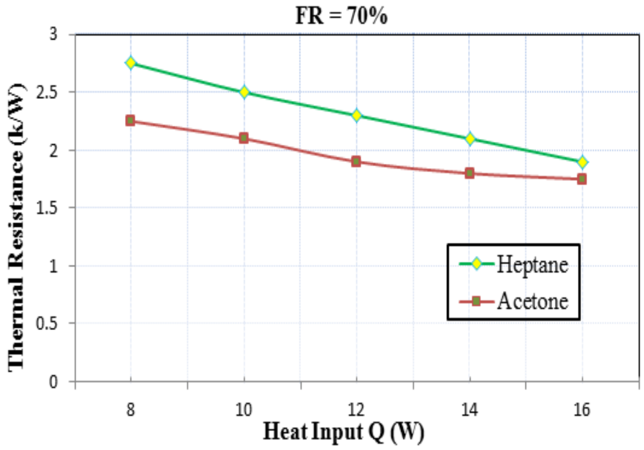

Figure 4.4: Variation of Thermal Resistance with Heat input for Acetone and Heptane

4.5 Effect of Fill Ratio on Heat Transfer Coefficient for Acetone

Figure 4.5shows the variation of heat transfer coefficient with heat input for acetone working fluid at different Fill Ratio. From figure it is clear that heat transfer coefficient is increases with increase heat inputs for all filling ratio. As the temperature difference between evaporator and condenser is decreases for acetone the heat transfer coefficient will increases. It is observed that at 60% fill ratio heat transfer coefficient is higher comparedto other fill ratio shows the best performance of PHP.

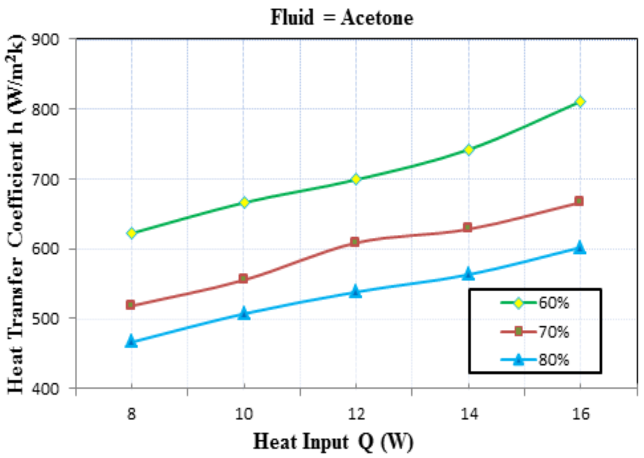

Figure 4.5: Typical Variation of Heat Transfer Coefficient with Heat Input Power at Different Fill Ratio for Acetone

4.6 Effect of Heat input on Heat Transfer Coefficient for Acetone and Heptane

Figure 4.6shows the variation of Heat Transfer Coefficient with heat input power for different working fluid at 70% fill ratio. From figure seen that heat transfer coefficient increases with increase in heat input power for both working fluids. It is observed that acetone is having higher heat Transfer Coefficient compared to heptane. As temperature difference between evaporator and condenser is decreases for acetone the heat transfer coefficient will increases.

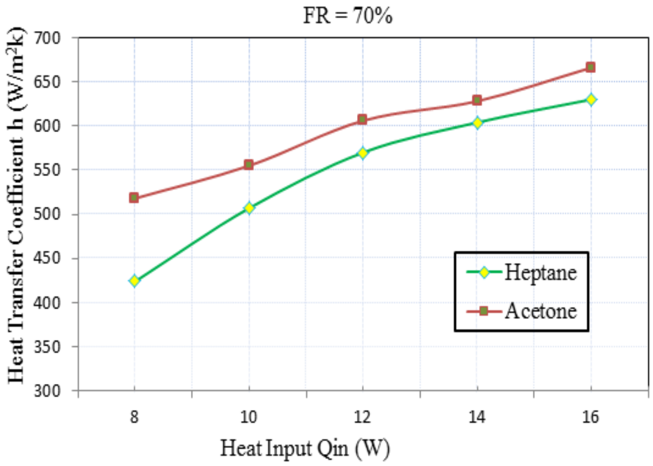

Figure 4.6: Variation of Heat input with Heat Transfer Coefficient for Acetone and Heptane

5. Conclusions

In the present work, the experimental analyses are carried out on a single loop PHP. The effects of working fluid, fill ratio and Heat Input Power on Design Parameters of Pulsating Heat Pipe are studied.

From these experimental analyses the following conclusions are drawn:

1) The temperature difference between evaporator and condenser is found to be lower for acetone as compared to heptane.
2) When heat input increases the thermal resistance isdecreases and heat transfer coefficient will be increases for all fill ratio.
3) Fluid circulation velocity is increase when the heat input increases.
4) Acetone is the most suitable working fluid for PHP operation when compared to heptane.
5) At a fill ratio of 60%, the PHP is found to exhibit better heat transfer characteristics for acetone.
6) At a fill ratio of 70%, the PHP found heat transfer capability for heptane.

Nomenclature

Q_{in}Heating power input(W)
FR Filling ratio (%)
R_{th}Thermal resistance (^{0}C/W)
T Temperature (^{0}C)
Te Temperature of evaporation section (^{0}C)
Tc Temperature of evaporation section (^{0}C)
Ts Temperature of boiling point (^{0}C)
*Te*Temperature of condenser section (^{0}C)
Cp Specific heat (KJ/kg·K)
H_{fg} Latent heat of evaporation (KJ/kg)
t time (s)
h = Convective heat transfer coefficient (W/m^{2}k)
A_s = Surface area of the tube (mm^2)

Greek Symbols
ρ_l *Liquid* density (kg/m^3)
ρ_v *Vapor* density (kg/m^3)
σ Surface tension(N/m)

υ Dynamic viscosity (Pa·s)
λ Thermal conductivity(W/m-k)

References

[1] Akachi, Structure of a heat pipe. US Patent No. 4921041, 1990.
[2] Khandekar S., Mamelli M. and Marengo M., "An Exploratory Study of a Pulsating Heat Pipe Operated with a Two Component Fluid Mixture", ASME Heat and Mass Transfer conference, IIT Madras, 2011.
[3] S. Khandekar and Manfred G., "Pulsating heat pipe: Attractive entrants in the family of closed passive two-phase systems", Journal of Energy and Mass Transfer, vol. 26,pp. 99-115, 2004.
[4] Mamelli M., Marengo M. and Zinna S., "Numerical model of a multi-turn Closed Loop Pulsating Heat Pipe: Effects of the local pressure losses due to meanderings", Journal of Heat and Mass Transfer, vol. 55, pp.1036–104, 2011.
[5] P. Meena, S. Rittidech and P. Tammasaeng, "Effect ofEvaporator Section Lengths and Working Fluids onOperational Limit of Closed Loop Oscillating Heat Pipeswith Check Valves (CLOHP/CV)", American Journal of Applied Sciences, vol. 1, pp.133-136, , 2009.
[6] Stéphane Launay, Valérie Sartre, Jocelyn Bonjour, "Parametric analysis of loop heat pipe operation: Literature review", International, Vol. 46, pp. 621– 636, July 2007.
[7] Honghai Yang, S. Khandekar, M. Groll, "operational limit of closed loop pulsating heat pipes", Applied Thermal Engineering 28, pp. 49-59, 2008
[8] Mauro Mameli, Sameer Khandekar, "Flow patterns and corresponding local heat transfer coefficients in a pulsating heat pipe", proceedings of the 29th National Heat Transfer Conference of Italy, pp. 20-22, June 2012.
[9] R. Manimaran, K. Palaniradja, N. Alagumurthi, J. Hussain, "Factors affecting the thermal performance of heat pipe", JERS, Vol. III, pp. 20-24, April-June, 2012.
[10] Pramod R. Pachghare, Ashish M. Mahalle, "Effect of pureand binary fluids on closed loop pulsating heat pipethermal performance", 3rdNirma University InternationalConference, vol. 51, pp. 624-629, 2012.
[11] Rama Narasimha, K. Rajagopal, M. S. Sridhara, S.N., "Influence of Heat Input, Working Fluid and Evacuation Level on the Performance of a Pulsating Heat Pipe", Journal of Applied Fluid Mechanics, Vol. 5, No. 2, Issue 10, 2012.
[12] R. Naik, V. Varadarajan, "Experimental Investigation and Performance Evaluation of a Closed Loop Pulsating Heat Pipe", Journal of Applied Fluid Mechanics, Vol. 6, pp. 267-275, 2013.

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