

EXPERIMENTAL INVESTIGATION OF VERTICAL ORIENTATION CLOSED-LOOP PULSATING HEAT PIPE WITH DIFFERENT DIMENSION

Mr. Balu K. Chavhan¹ Prof. C.B. Kothare², Prof. K.S. Raizada³,

¹Student M.Tech. HPE, S.S.P.A.C.E, Wardha, RTMNU, ²Principal, Agnihotri School of Technology (Polytechnic) Wardha, ³Department of Mechanical Engineering S.S.P.A.C.E, Wardha, Rashtrasant Tukadoji Maharaj Nagpur University

ABSTRACT:

The vertical closed-loop pulsating heat-pipe systems with different dimension and heat input. Numerous test systems were constructed using copper capillary tubes with assorted inner diameters, evaporator lengths, CLPHP. It is very efficient device for dissipating heat from the device. But new technology introduces which is nothing but Pulsating Heat Pipe. In this experiment three different configurations of copper capillary tubes having internal diameters 1.5mm, 2.0 and alternate internal diameter. The experiments are conducted on vertical orientations for different heat loads varying from 10 W to 130 W in steps of 10 W. The PHP is tested on Ethanol, as working fluids for different fill ratios viz. 30%, 50%, and 70%, the temperature distribution across the heat pipe was measured and recorded using thermocouples. The thermal resistance and the overall heat transfer coefficient are evaluated. The experimental results demonstrate the heat transfer characteristics, lower thermal resistance and higher heat transfer coefficient of CLPHP are found to be better at a fill ratio of 50% for different heat input and also the thermal performance of alternate internal diameter i.e. 1.5mm and 2mm of pulsating heat pipe gives better result over the uniform diameter of CLPHP.

KEYWORDS: Pulsating heat pipe, Fill Ratio, Working fluids.

1. INTRODUCTION

There is a vast requirement of miniature equipment in electronic devices for cooling purpose so pulsating heat pipe can significantly used for cooling purpose. Pulsating heat pipes (PHPs) or oscillating heat pipes (OHPs) are relatively young members in the family of heat pipes. The basic structure of a typical pulsating heat pipe consists of meandering capillary tubes having no internal wick structure. It can be designed in at least three ways:

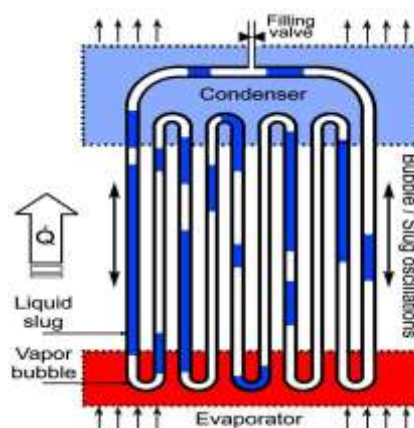


Fig 1.2 Schematic of pulsating heat pipe

- a. Open loop system,
- b. Closed loop system and
- c. Closed loop pulsating heat pipe (CLPHP) with additional flow control check valve

It has been shown by previous studies that a closed loop pulsating heat pipe is thermally more advantageous than an open loop device because of the possibility of fluid circulation. Although a certain number of check valves have shown to improve the performance, miniaturization of the device makes it difficult and expensive to install such valve(s). Therefore, a closed loop device without any check valve(s) is most favourable from many practical aspects. Studies have already identified various design parameters affecting the performance of CLPHPs. There are various parameters which affect the performance of the closed loop pulsating heat pipe includes,

- i) Internal diameter of tube.
- ii) Filling ratio of working fluid in tube.
- iii) Total numbers of turns.
- iv) Input heat flux.
- v) Device orientation
- vi) Thermo-physical properties of the working fluid

The closed passive system thus formed is evacuated and subsequently filled up partially with a pure working fluid, which distributes itself naturally in the form of liquid–vapour plug and slugs inside the capillary tube. One end of this tube bundle receives heat transferring it to the other end by pulsating action of the liquid vapour slug system. When the heat is supplied to the heat receiving portion (evaporator section) due to temperature difference there exist a temperature gradient which are responsible for the heat transfer. Due to supplied heat the vapour slug from due to low pressure side towards the heat radiating portion (condenser section) and again the liquid slug from the alternate cooling and heating are done. The generating and collapsing bubbles act as pumping elements transporting the entrapped liquid slugs in a complex oscillating–translating–vibratory fashion; a direct consequence of thermo-hydrodynamic coupling of pressure/temperature fluctuations with the void fraction (mal-) distribution.

There are various parameters which affect the performance of the closed loop pulsating heat pipe like orientation, internal diameter, length of tubes, flow of working fluid, numbers of tubes etc. The effect of varying diameter and flow patterns over a performance of closed loop pulsating heat pipe to enhance heat transfer coefficient is being principle candidate scrutinizes.

Pulsating heat pipe is miniature in size as well as more efficient than conventional PHP for cooling and thermal management.

2. EXPERIMENTAL SETUP AND PROCEDURE

2.1 INTRODUCTION

The experimental setup three kinds of configurations were designed for the PHPs. All three types of PHPs were made of copper capillary tubes. The tubes were bent into four turns with the bending radius of 10 mm, and joined end to end, forming an eight-channel serpentine loop. The total height of the closed loop

pulsating heat pipe is 220 mm and total width 130mm. The evaporator, adiabatic and condenser section lengths are 60 mm, 80mm and 80 mm respectively. The valve for filling working fluid is arranged at the top of vertical tube of the PHPs, for the evacuation and filling assembly. The experimental setup consists of a closed loop PHP, temperature recorder, power supply unit, and water tank cooling system for condenser. Both the evaporation and adiabatic sections were well thermally insulated by the proper insulation materials.

2.2 EXPERIMENTAL SETUP

Fig. Shows the schematic diagram of the experimental setup. In this setup, copper is used as the capillary tube material in each section with inner diameter of different configuration having internal diameter 1.5mm, 2mm and alternate internal diameter, the outer diameter of 2.9mm, 3.6mm and alternate varying channel diameter respectively. In order to adiabatic section is connected between evaporator and condenser sections for a length of 80 mm. In the present investigation, the evaporator section consists of oil bath heater of 0-500 W is employed during the experiments for heating the working fluid. Six K type thermocouples are used for the temperature measurement. The operating temperature range of these K type thermocouples is 0 to 2400 °C. Two thermocouples are fixed in the evaporator section and two in condenser section, also two in adiabatic section similarly one in the oil bath and two are measured the inlet and outlet temperature of water at condenser section. The temperatures measured by two thermocouples in the evaporator section are named as T1 and T2. The temperatures measured by two thermocouples in the condenser section are named as T4, and T5 respectively.

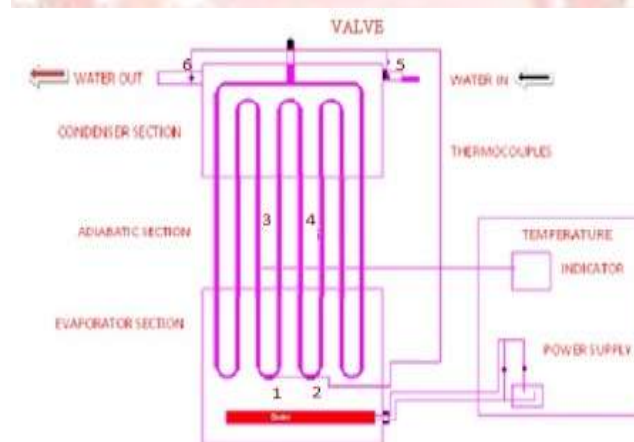


Figure.2.1 Schematic diagram of experimental setup CLPHP

The thermocouples are fixed on the walls of the copper tube. The thermocouples temperature is measured with help of digital temperature indicator which is mounted on control panel. The experimental setup consists of a closed loop PHP, temperature recorder, power supply unit, and water tank cooling system for condenser. Both the evaporation and adiabatic sections were well thermally insulated by the proper insulation materials. The heating power is provided by a carefully designed power supply unit. Heating was done by oil bath and cooling by water tank. The power meter measures the AC voltage, the current and the corresponding power simultaneously. The Filling Ratio was maintained at 30%, 50% and 70% for each configuration. The heating

configuration was bottom heat orientation ($+90^{\circ}$). Six K-type thermocouples were attached to the wall of the PHP.

2.3 EXPERIMENTAL DESCRIPTION

Figure. Shows the three kinds of configurations were designed for the pulsating heat pipe (PHPs). All the three types of the PHPs were made of copper capillary tubes are as follows.



Figure 2.2 Experimental Schematic of the PHP.

- 1) The php in case A is normal php with a uniform inner diameter of 1.5mm
- 2) The php in case B is again normal with uniform internal diameter of 2mm
- 3) The php in case C is again normal with uniform internal diameter of 2mm

The differences among the three types of the PHPs lay on the variation in channel diameter along the flow path.

2.3.1 The PHP in case A is normal PHP with a uniform inner diameter of 1.5mm

2.3.2 The PHP in case B is again normal with uniform internal diameter of 2mm:

These two configurations are fabricated by same procedure as follows,

Copper tubes are turn into U tube having 10mm radius according to length of evaporator and condenser i.e.60mm and 80mm these 8mm additional for fitting into acrylic plate. 8mm thick acrylic plate is used for baffle plate. The size of acrylic plate is 170*40*8mm.holes are drilled in to acrylic plate vertically accordingly internal diameter i.e. 1.5mm and 2mm. Holes are clean by using thinner.8mm counter bore are done as per external diameter of copper tube, Copper U tubes inserted into acrylic plate then sealed with araldite and M seal. While sealing care is taken about choking and leakage .then Condenser coil is fitted in to cooling bath and holes are sealed .two thermocouples are soldered in adiabatic section ,two thermocouples at inlet and outlet of the condenser And two at evaporator section.

2.3.3 PHP C is an alternate internal diameter of 1.5 and 2mm:

The PHP in case C were provided with some special configurations helpful to initiate and sustain the circulatory flow. For the PHP C, the inner diameter was designed to vary alternately. The inner diameters of the two adjacent tubes were 1.5mm and 2 mm respectively. These tubes joined end to end by soldering at refrigeration maintenance shop. Remaining procedure is same like other two configuration. 3/4 inch valve is fitted at the top of each setup for evacuation and filling working fluid. The circulatory flow is desirable because the circulation of the working fluid enhances the capability for the working fluid to transport heat from the evaporation to the condensation zone.

In this study, one improved PHPs with special configurations, with alternately varying channel diameter, were designed and testified to be beneficial to forming and sustaining a circulatory flow. At 50% filling ratio vertically bottom heating mode are use.

Following procedure is adopted during the present transient and steady state experimentation:

- Before filling the working fluid, air is blown inside the heat pipe to ensure that there is no fluid present inside the CLPHP.
- CLPHP is filled with working fluid using a syringe for the required amount. The experiments are conducted for filling ratio 50% with three kinds of configuration respectively.
- The CLPHP is oil bath heated with the help of a power supply by using heater 500W
- The required amount of working fluid is then filled through a syringe by opening one end of the non-return valve such that the fluid directly enters the evaporator section.
- Now the air is filled through the filling valve provided on the brass tube using another syringe.
- The cooling water is allowed to the condenser section of PHP from the constant water bath and the amount of cooling water is controlled in such a way that the temperature rise of cooling water in the condenser is always between 10 C to 30 C.
- The temperature data logger is then switched on to record the temperature readings.
- The required wattage is set using the power supply unit. In the present work, the experiments were conducted by varying the heat inputs from 10W to 120W in steps of 10 W.
- Also same time note temperatures at different locations by rotating knob on control panel for every wattage.
- Repeat same procedure for other two configuration

3. RESULTS AND DISCUSSIONS

Experimental study on PHP indicated that three kinds of configuration is an important factor for the performance of PHPs. The result shows that, the thermal resistance decreases more rapidly with the increase of the heating power from 10 to 130W, whereas slowly decreases at input power above 80W. The thermal performance of set up C of pulsating heat pipe gives better result over the uniform diameter PHP with different filling ratios i.e. 30%, 50%, and 70%. The performance parameters of PHP like thermal resistance and heat transfer coefficient are would be evaluated for the above conditions. Working fluids are selected as ethanol. The graphs are plotted, in order to study, characteristics of the thermal resistance and average evaporator temperatures at different heat input for various internal diameter.

3.1 Effect of thermal resistance on the heat inputs in the CLPHP for filling ratio 30%

The Variation of thermal resistance over the heat inputs CLPHP for filling ratio 30% In case A, the tube diameter is uniform 1.5 mm the transport of the working fluid is not sufficient and the performance is poor.

In case B the tube diameter is uniform 2.0mm. In which thermal resistance is lower than PHP A. working of PHP B is better than PHP A, up to 80W thermal resistance decline greatly and after that increase in heat input thermal resistance start to increase.

In case C the tube internal diameter is varying alternately as 1.5mm and 2.0mm. The PHP C with varying diameter has the most excellent thermal performance among them. Among three PHP C have low thermal resistance; it can work at higher heat input than other two uniform type configuration i.e. up to 110 W.

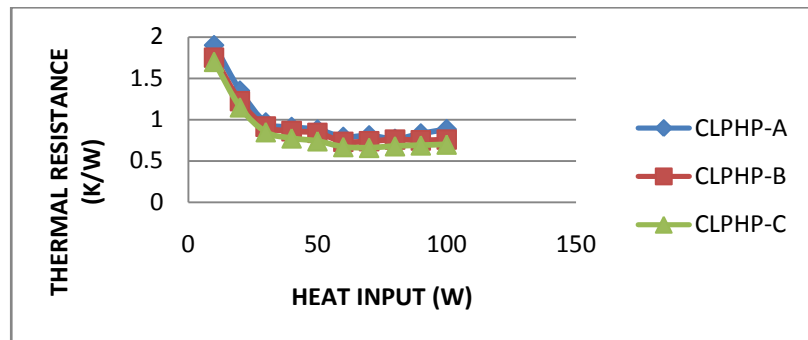


Figure. 3.1 Variation of thermal resistance over the heat inputs CLPHP.

3.2 Effect of thermal efficiency on the heat inputs in the CLPHP for filling ratio 30%

Efficiency comparison among three php is shown in fig 3.2 thermal resistance greatly affect on performance of php. The php C efficiency is better than php-A and B an it start to increase from initial and up to near about 100 W. after that descending up to dry out.

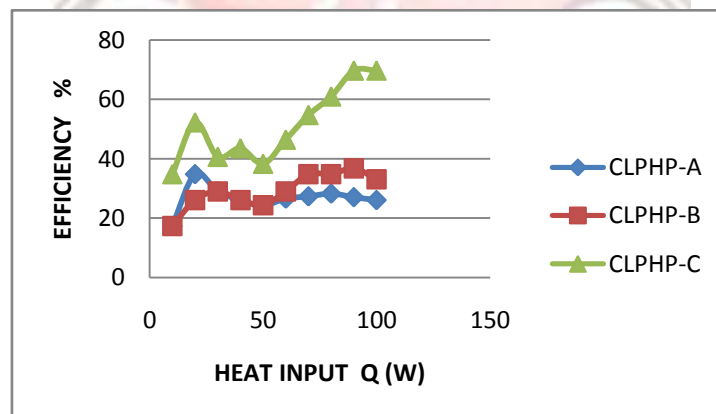


Fig 3.2 Variation of efficiencies among three CLPHP.

3.3 Effect of thermal resistance on the heat inputs in the CLPHP for filling ratio 50%

In case A, the tube diameter is uniform 1.5 mm, no circulatory flow takes place at low heat input, Because of the symmetry in flow path geometry. Slugs/ Bubbles only vibrate with low amplitude about a mean Position. Consequently, the transport of the working fluid is not sufficient and the performance is poor. As the heat Input is increased, the oscillation amplitude increases. When the heat input reaches certain Value, the bulk circulation starts, but periodically stops and starts in the same or opposite direction. After 80W thermal resistance is increases due to dry out and temperature of evaporator increases fast rate .also heating oil start to boil and vaporize.

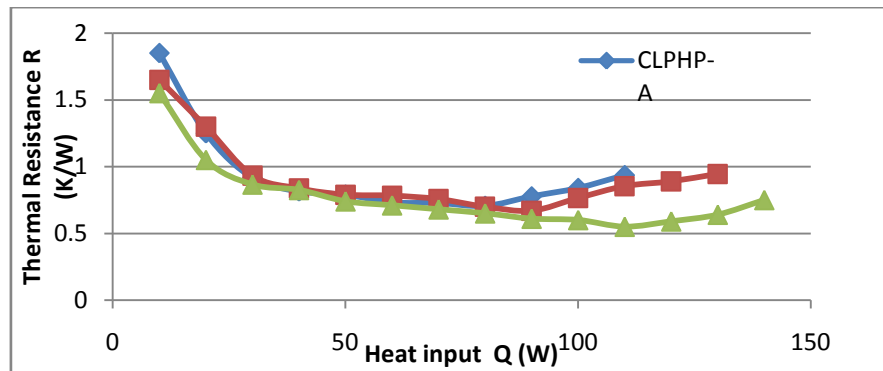


Fig. 3.3 Variation of thermal resistance over the heat inputs CLPHP.

In case B the tube diameter is uniform 2.0mm. In which thermal resistance is lower than PHP A. working of PHP B is better than PHP A, up to 90W thermal resistance decline greatly and after that increase in heat input thermal resistance start to increase. Means there is a dry out condition start.

In case C the tube internal diameter is varying alternately as 1.5mm and 2.0mm. The PHP C with varying diameter has the most excellent thermal performance among them. Among three PHP C have low thermal resistance, it can work at higher heat input than other two uniform type configuration i.e. up to 110 W. in which circulatory flow are observed and remains in fixed direction which enhanced heat transfer coefficient. Due to alternate diameter vapor flow upward through 2mm diameter tube and come back through 1.5mm tube by gravity. After 120 W thermal resistance start increased and evaporator temperature also increase at fast rate because there is dry out condition initiated which near about stop the working of php.

Efficiency comparison among three php is shown in fig 5.6 thermal resistance greatly affect on performance of php. In case php A highest value is 31% and it is in between 30 to 50 W after that start to decline. In PHP B efficiency is better than php A it start to increase from initial and up to near about 90 W. after that descending up to dry out.

3.4 Effect of thermal efficiency on the heat inputs in the CLPHP for filling ratio 50%

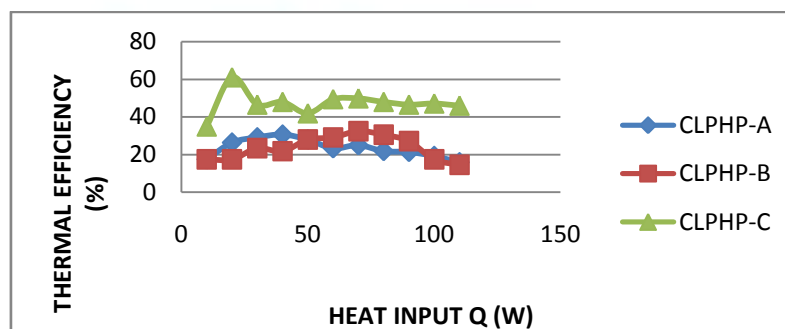


Fig. 3.4 Variation of efficiencies among three PHP.

In CLPHP C 1.5& 2mm alternate internal diameter are used whose efficiency is excellent than other two uniform configuration .it ascend from initially and maintained up to 110W. After that thermal resistance start to increases.

3.5 Effect of Thermal resistance on the heat inputs in the CLPHP for filling ratio 70%

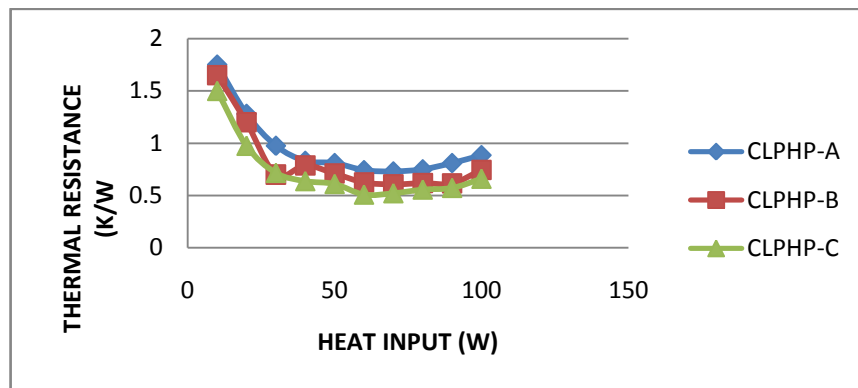


Figure. 3.5 Variation of thermal resistance over the heat inputs CLPHP.

Fig 3.5.shows Thermal resistance verses heat inputs in the CLPHP for filling ratio 70%, the thermal resistance of clphp-c rapidly decrease upto 60W When heat input increases the thermal resistance will decreases and heat transfer coefficient will be increases.

3.6 Effect of thermal efficiency on the heat inputs in the CLPHP for filling ratio 70%

Fig 3.6.shows of thermal efficiency on the heat inputs in the CLPHP for filling ratio 70% Efficiency comparison among three php is thermal resistance greatly affect on performance of php. In case -C better thermal efficiency in between 10 to 60 W after that start to decline and then increases. In php B efficiency is better than php-A and it start to increase from php middle from 50w and up to near about 90 W. after that descending up to dry out.

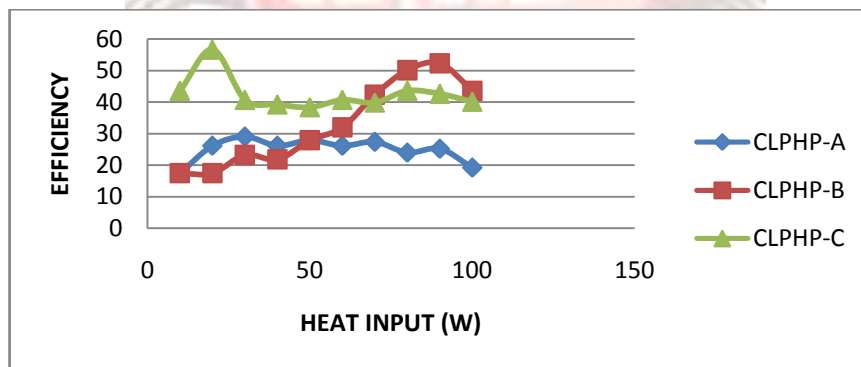


Figure. 3.6 Variation of efficiencies among three PHP.

3.7 Identifying the Optimum Thermal Efficiency and Minimum thermal Resistance with different Fluid Fill Ratios.

Comparative plot of thermal resistances and thermal efficiency at varying different fill ratio of working fluid as a percentage of evaporator volume for the working fluids with the heat. Loads of 10 W and 130 W are shown in the figure above. The effect of fill ratio of working fluid on heat transfer coefficients and thermal resistances are shown in Fig. above In case of ethanol as working fluid it is observed that it shows maximum value of heat transfer coefficient and minimum value of thermal resistance at 50% fill ratio. Lower 30% fill ratio results in lower values of heat transfer coefficients and higher values of thermal resistances than that of 50%. So, it can easily be stated that for ethanol as the working fluid, a pulsating heat pipe will perform its best at 50% fill ratio.

3.7.1 Effect of Thermal resistance in the CLPHP-A-B-C for filling ratio 30%, 50% and 70%

The thermal performance of C type configuration shows better improvement. From various configuration it observed that the internal diameter of closed Loop Pulsating heat pipe increases leads to decreases in thermal resistance and improved in overall thermal performance. The filling ratio is a critical parameter, which needs to be optimized to achieve maximum thermal performance and minimum thermal resistance for a given operating condition. From this experimental setup we are conclude that at 50% filling of CLPHP give the optimum result.

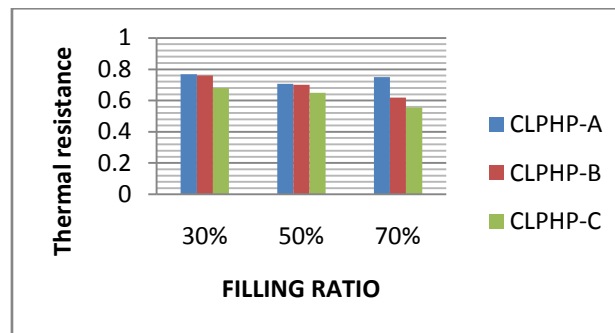


Figure. 3.7 Variation of thermal resistance over the heat inputs CLPHP with different filling ratio.

3.7.2 Effect of Thermal efficiency in the CLPHP-C for filling ratio 30%, 50% and 70%

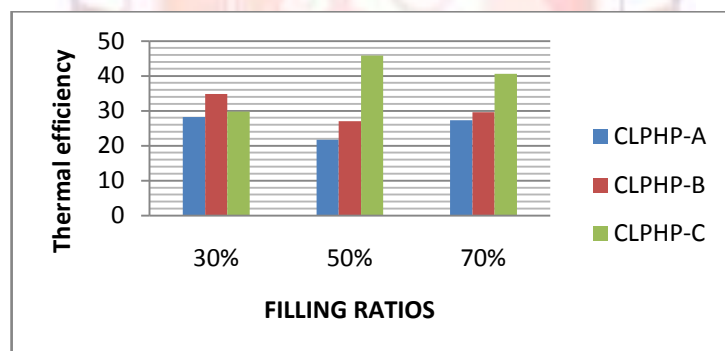


Figure. 3.8 Variation of efficiencies among three PHP with different filling ratio.

in overall heat transfer coefficient compare with the configurations A and B, also configuration C shows better thermal performance when fill ratio is 50%.

3.8 Thermal Resistance

The Thermal Resistance of PHP is given by Values of thermal resistance in present work are near about close to reference work. Various flow patterns, such as bubble-liquid slug flow, semi-annular flow and annular flow occur in different working conditions.

$$R = \frac{T_e - T_c}{Q} \quad (\text{K/W})$$

3.9 Efficiency of PHP

Thermal efficiency of closed loop pulsating heat pipe is given by

$$\eta = \frac{Q_{\text{out}}}{Q_{\text{in}}} \times 100$$

3.10 Effect of Heat Transfer Coefficient

The heat transfer coefficient of a PHP is given by [Faghri (1995)]

$$h = \frac{Q}{A_s(T_e - T_c)} \text{ (W/m}^2 \text{ K)}$$

4. CONCLUSION

1. In the present work, the experimental investigations are carried out on a closed loop PHP. The effects of heat input, working fluid and fill ratio on the performance of PHP are studied. The results of the present study are summarized as follows:
 - A. The heat transfer coefficient of CLPHP with different heating input shows. Maximum value and lower thermal resistance with increasing the filling ratio. The thermal resistance for filling ratio 50% shows less thermal resistance compare with 30% and 70 %.
 - B. The thermal performance of C type configuration shows better improvement in overall heat transfer coefficient compare with the configurations A and B, also configuration C shows better thermal performance when fill ratio is 50%.
 - C. From various configuration it observed that the internal diameter of closed Loop Pulsating heat pipe increases leads to decreases in thermal resistance and improved in overall thermal performance.
2. The thermal resistances have the results of $R_{clphp-A} \geq R_{clphp-B} \geq R_{clphp-c}$. This condition is occurs up to 80 W and above the 80 W the thermal Resistance of CLPHP-C is increased slightly. Also thermal efficiency of closed loops pulsating heat pipe slightly decrease.
3. The thermal resistance of closed loop pulsating heat pipe with ethanol as working fluid decreases with increase in the heat input hence the thermal performance of closed loop pulsating heat pipe increases with increase in the heat input. Also it was found from the experimental results that thermal resistance of closed loop pulsating heat pipe with ethanol as working fluid increases first and then decreases

REFERENCES :

1. Brian Holley, Amir Faghri, " *Analysis of pulsating heat pipe with capillary wick and varying channel diameter*. International journal of heat & mass transfer 48(2005)2635-2651
2. B.Y. Tong, T.N. Wong, K.T.Ooi, " *Closed-loop pulsating heat pipe*" Applied thermal engineering 21 (2001) 1845-1862.
3. Honghai yang Sameer Khandekar and Manfred Groll " *operational characteristics of flat plate closed loop Pulsating Heat Pipe*" 13th International Heat Pipe Conference (13th IHPC), Shanghai, China, September 21-25, 2004.
4. Jian Qu a, Huiying Wua, Ping Cheng a, Xiong Wang, " *Nonlinear analysis of temperature oscillation in close loop pulsating heat pipe*". International journal of heat & mass transfer 52(2009)3481-3489.
5. J.L. Xu a, Y.X. Li a,b, T.N. Wong , " *High speed visualization of close loop pulsating heat pipe*". International journal of heat & mass transfer 48(2005)3338-3351

6. Khandekar S., M.Groll “*Introduction to pulsating heat pipe*”; electronic cooling volume9 No2, may 2003
7. Niti Kammuang-Luea; Phrut Sakulchangsatjataia; Pradit Terdtoona; D. Joseph Mookb, “*Correlation to Predict the Maximum Heat Flux of a Vertical Closed-Loop Pulsating Heat Pipe*” Heat Transfer Engineering, 30(12):961–972.
8. P. Charoensawan., S. Khandekar Manfred Groll, Pradit Terdtoon “*Closed loop pulsating heat pipes Part A: parametric experimental investigations*”. Applied Thermal Engineering 23 (2003) 2009–2020
9. P. Charoensawan, S. Khandekar Manfred Groll, Pradit Terdtoon “*Closed loop pulsating heat pipes Part B: visualization & semi-empirical modeling*”. Applied Thermal Engineering 23 (2003) 2021–2033
10. Shi Liu Jigtao Li Xiagum Dong. “*Experimental study of flow patterns and improved configuration for pulsating heat pipe*” journal of thermal science 1003-2169(2007)01-0056-07
11. S. Khandekar, Nicolas Dollinger, Manfred Groll “*Understanding operational regimes of closed loop pulsating heat pipes: an experimental study*”. Applied Thermal Engineering 23 (2003) 707–719.
12. S. Khandekar Manfred Groll Institute for Kernenergetik und Energy system, University Stuttgart 70569 Stuttgart, Germany 5th Minsk International Seminars (Heat Pipes, Heat Pumps and Refrigerators), Minsk, Belarus, 2003.
13. Sameer Khandekar and Manfred Groll 9th International *Heat Pipe Symposium*, Kuala Lumpur, Malaysia, November 17-20, 2008.
14. Sameer Khandekar and Manfred Groll Roadmap to Realistic Modeling of Closed Loop Pulsating Heat Pipes 49th International Heat Pipe Symposium, Kuala Lumpur, Malaysia, November 17-20, 2008
15. Sameer Khandekar and Manfred Groll On the definition of heat pipes: an overview Proc. 5th Minsk International Seminar (Heat Pipes, Heat Pumps and Refrigerators), Minsk, Belarus, 2003
16. Sameer Khandekar Prof. Dr.-Ing. Habil. M. Groll (2004) “*thermo- hydrodynamics of closed loop pulsating heat pipe* Institute for Kernenergetik and Energie systeme University Stuttgart.
17. Sameer Khandekar and Manfred Groll and vivak luckchoura “*an introduction to pulsating heat pipe*” electronic cooling volume 9 no.2 may 2003.
18. S. Khandekar (a), M. Groll (a), P. Charoensawan (b) and P. Terdtoon (b) *Pulsating Heat Pipes: Thermo-fluidic Characteristics and Comparative Study with Single Phase Thermosyphons Proceedings of 12th International Heat Transfer Conference, Vol. 4, pp.459-464, Grenoble, France, 2002*
19. Sanka VVSNS manyam and manmohan pandey.” *Two-phase flow modelling in Closed Loop Pulsating Heat Pipes*” 13th International Heat Pipe Conference (13th IHPC), Shanghai, China, September 21-25, 2004.