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Thermal Performance Analysis of Close Loop Pulsating Heat Pipe with Varying Internal Diameter at Various Heat Inputs

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***Abstract* - Pulsating Heat Pipes (PHP) or Oscillating Heat Pipes are the young members of energy conversion family. They are most effective and are able to carry maximum heat from the source. But still they are under research and needs more reliable thermal performance data in order to validate its working phenomenon. Pulsating heat pipe are continuously under research which evolves new generated solution in order to fulfill present requirements of energy conversion solutions.**

Pulsating (or oscillating) heat pipes (PHP or OHP) are new two-phase heat transfer devices that rely on the oscillatory flow of liquid slug and vapor plug in a long miniature tube bent into many turns. The unique feature of PHPs, compared with conventional heat pipes, is that there is no wick structure to return the condensate to the heating section; thus, there is no counter current flow between the liquid and vapor. Heat addition and rejection and the growth and extinction of vapor bubbles drive the flow in a PHP. Applications of pulsating heat pipes are in HVAC, space applications (limited).

In this paper Closed Loop Pulsating Heat Pipe is considered under experimentation. Internal diameter of PHP is varied and thermal readings are taken to find thermal resistance and efficiency of PHP. For that purpose we have considered three configurations as 1.5mm internal diameter, 2mm internal diameter and 1.5mm with 2mm alternate internal diameter. There thermal resistance and efficiency is compared with each other.

***Index Terms* - PHP, OHP, Thermal Resistance, Thermal Efficiency.**

1.INTRODUCTION

As per the need of industry for the cooling of electronics equipment the pulsating heat pipe are used now days in order to have efficient energy conversion or heat transfer. Pulsating heat pipes (PHPs) or oscillating heat pipes (OHPs) are the latest techniques, which are used for the cooling. It has three different types which consist of meandering capillary tubes with no internal wick structure. There types are as follows.
1) Open loop Pulsating Heat Pipe
2) Closed loop Pulsating Heat Pipe
3) Closed loop pulsating heat pipe (CLPHP) with additional flow control check valve

As we know that the closed loop PHP are more reliable and have better thermal efficiency than the open loop PHP. The main cause behind that is the fluid flowing characteristics of closed loop PHP. By conducting various experimentations, it is found that the performance of PHP can be improved more by using check valves, whoever the shape and size of the PHP makes it difficult to install these valves also these valves are costlier. Hence at most of the places check valves are not installed as PHP is cheaper without check Valves to perform various experimentations. The design parameters which affect the performance of closed loop PHP are identified by research before in order to have better efficiency. These parameters are listed below. These parameters are having ability to improve or decrease the performance of the Closed

Loop PHP. Hence they should be controlled well.
1. Inner diameter of the Pulsating Heat Tube.
2. Number of Turns in PHP.
3. Flowing Fluid Quantity.
4. Device Positioning.
5. Heat flux of the tube at the inlet
6. Various thermal and fluid properties of flowing fluid.

The heat flowing tube is evacuated and then working fluid is filled to insure efficient heat transfer. This liquid is evaporated while absorbing heat at one end and condensed at other end while supplying heat to other end.

When heat is supplied to the one of the end of the PHP i.e. evaporating system, the liquid absorbs the heat and get converted into vapor which flows to the another end i.e. condenser section. As we know that heat transfers from higher temperature to lower temperature means temperature gradient is responsible for heat transfer. Hence vapor flows towards condensation section by capillary or pulsating action. Bubbles formed in PHP create pumping action which creates fluid flow inside the tube. N this way the PHP works and used for energy conversion.

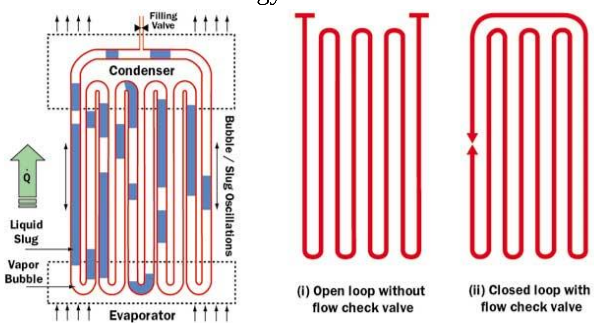

Figure 1: Line Diagram of PHP and its different types [Groll et al 2003]

2. LITERATURE SURVEY

P. Charoensawan et.al [1] investigated that the "*Closed loop pulsating heat pipes Part A: parametric experimental investigations*". In their article they have experimentally studied CLPHP thermal performance depends on various parameters like internal diameter of tube, number of turns, working fluid and inclination angle of the device. CLPHPs are made of copper tubes of internal diameters 2.0 and 1.0 mm, heated by constant temperature water bath and cooled by constant temperature Water ethylene glycol mixture (50% each by volume). Shi liu et al [2]; They have carried out the "Experimental study of flow patterns and improved configuration for pulsating heat pipe". In their work two special configurations are taken for study, one with alternately varying channel diameter, the other equipped with one section of thicker tube, a series of experiments were performed on three types of closed loop pulsating heat pipe (PHPs), intending to investigate various kinds of flow patterns, and to develop some improved configurations for the PHPs.

B.Y.Tong.et.al. [3], Included that experimental studies on "*Closed-loop pulsating heat pipe* "In their study dimension was taken to perform the experimentation as ID of tube 1.88 mm, filling ratio 60% of total volume. It is observed that during the startup period the working fluid oscillates with large amplitude but at steady state it circulates in the tubes.

Khandekar et al. [4] investigated that the "Thermal performance of closed loops pulsating heat pipe at various heat input" In their study, they have studied at least three thermo-mechanical boundary conditions i.e. internal tube diameter, input heat flux and the filling ratio. Experiments were conducted on a PHP made of copper capillary tube of 2-mm inner diameter.

P.Charoensawan et.al [5] investigated that the experimentally studies on "Closed loop pulsating heat pipes Part B: visualization & semi- empirical modeling". In their work, total of three set-ups were built, i.e. CLPHP with Le = 50 mm with 10 turns, Le = 50 mm with 28 turns and Le =150 mm with 11 turns (Le = Lc = La in all cases, as in Part A). All CLPHPs were tested with R-123 as the working fluid at a fixed filling ratio of 50% and inclination angles of 0^{O},30^{O}, 50^{O}, $70^{O}$and 90^{O} from the horizontal axis. From the outlet temperature and mass flow rate of the coolant, the heat transfer could be calculated.

2.1 Outcome from literature Survey

Pulsating heat pipe is a passive device heat is transfer in two phase phenomenon i.e. sensible heat and latent heat by liquid slugs and vapor plugs. Vapor bubbles move upward through hot tubes from evaporator and liquid come back in adjacent tube from condenser. From literature survey the working of PHP affected by various parameters, like internal diameter, heat input, and thermo-physical properties of working fluid, inclination angle, and number of turns, filling ratio and device orientation. There is a vast requirement of miniature equipment in electronic devices for cooling purpose so pulsating heat pipe can significantly used for cooling purpose.

3. EXPERIMENTAL DESCRIPTION

Figure 2 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.

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

Figure 2: Experimental Schematic of the PHP

Table 1: Specification of New Design pulsating Heat Pipe

Sr. No	Parameter	First configuration	Second configuration	Third configuration
1	Evaporator Length (Le)	60mm	60mm	60mm
2	Adiabatic Length (Lad)	80mm	80mm	80mm
3	Condenser Length (Lc)	80mm	80mm	80mm
4	Total Length (Lt)	220mm	220mm	220mm
5	Effective Length (Lef)	150mm	150mm	150mm
6	Inner Radius (Ri)	0.75m	1mm	1.60mm
7	Internal diameter	1.5mm	2mm	2mm &1.5mm
8	Outer diameter	2.90mm	3.6mm	3.25mm
9	Axial Angle	(90^0)	(90^0)	(90^0)

3.1. The PHP in Case A is Normal PHP with a Uniform Inner Diameter of 1.5mm

Copper tubes are turn into U tube having 15mm radius according to length of evaporator, adiabatic and condenser i.e.60mm, 80mm and 80mm these 16mm additional for fitting into acrylic plate. 8mm thick acrylic plate is used for separating different section i.e. evaporator & condenser section

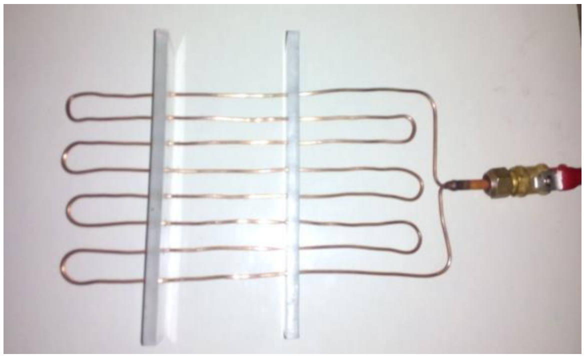

Figure 3: First configuration (1.5mm uniform internal diameter)

The size of acrylic plate is 170*40*8 mm holes are drilled into 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.

3.2 The PHP in Case B is again Normal with Uniform Internal Diameter of 2mm

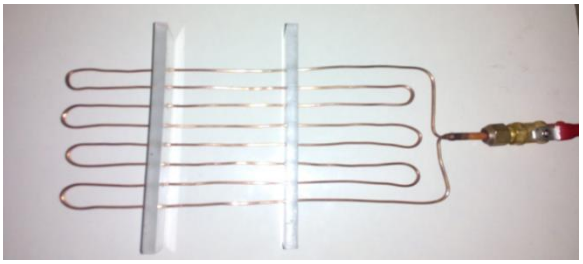

Figure 4: Second configuration (2mm uniform internal diameter)

These second configurations are fabricated by same procedure as follows, Copper tubes are turn into U tube having 15mm radius according to length of evaporator, adiabatic and condenser i.e.60mm, 80mm and 80mm these 16mm additional for fitting into acrylic plate. 8mm thick acrylic plate is used for separating different section i.e. evaporator & condenser section. The size of acrylic plate is 170*40*8mm.holes are drilled into 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.

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/brazing 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.

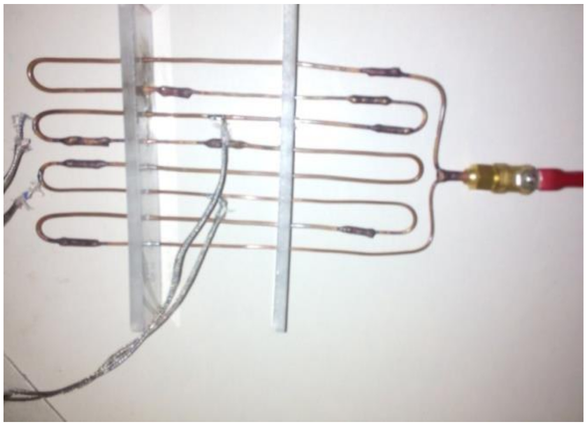

Figure 5: Third configuration (1.5mm and 2mm alternate internal diameter).

IV. RESULT GENERATION FOR VARIOUS CASES

4.1 Effect of thrmal resistance on the heat inputs in the CLPHP for filling ratio 50%

Fig. 6 shows 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. 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.

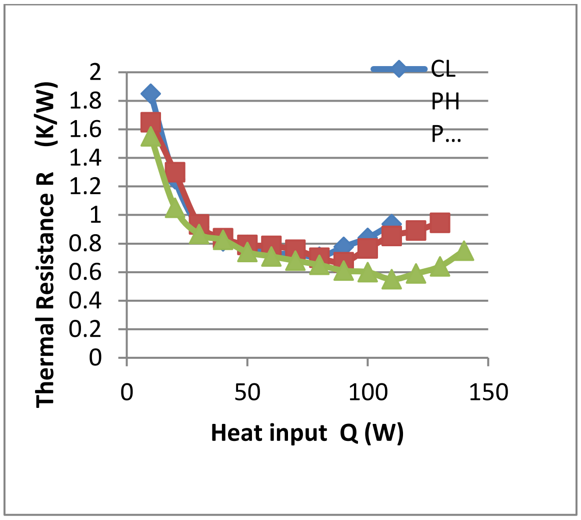

Figure 6: Variation of thermal resistance over the heat inputs CLPHP.

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.

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.

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

Efficiency comparison among three PHP is shown in fig 7 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 an it start to increase from initial and up to near about 90 W. after that descending up to dry out.

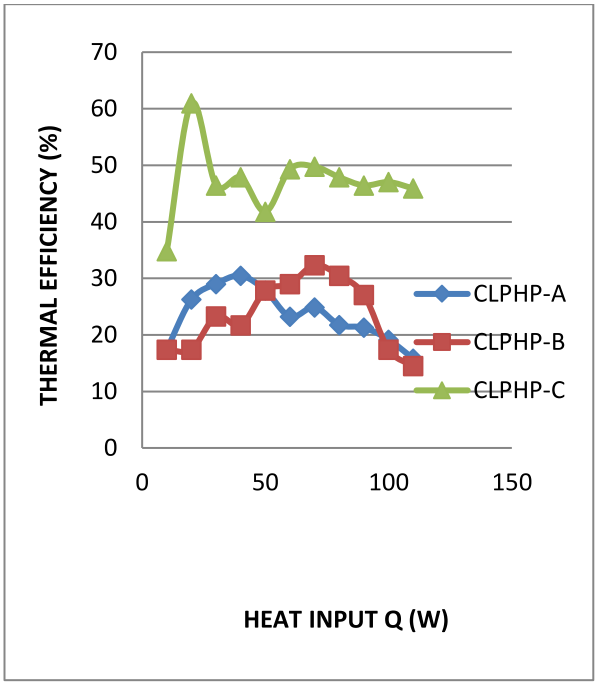

Figure 7: Variation of efficiencies among three CLPHP

In PHP 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.

4.3 Effect of condenser outlet temperature on the heat inputs in the CLPHP for filling ratio 50%.

Figure 8 shows heat input verses condenser water outlet temperature in case A highest temperature gain is 39 ºC at 80 W. Incase B highest temperature gain is 42 ºC at 90 W. And again in configuration C highest temperature achieved is 58ºC at110 W in which from beginning higher the heat transfer coefficient and lower is the thermal resistance.

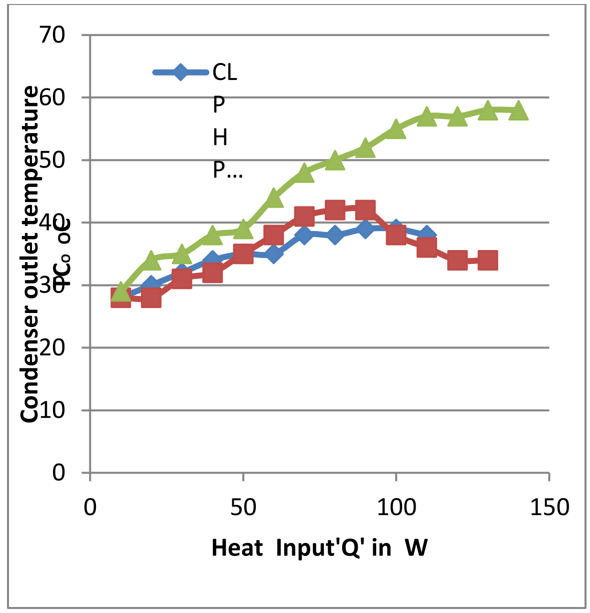

Figure 8: Variation of condenser temperature among three CLPHP.

V. CONCLUSION

1] The thermal performance of set up C of pulsating heat pipe gives better result over the uniform diameter PHP in the following parametric study.

i) Thermal resistance of PHP 'C' is less than uniform diameter CLPHP

ii) Thermal efficiency of PHP 'C' gives better efficiency over the uniform diameter PHP.

iii) The heat input of PHP increases the dry out zone of the uniform diameter PHP is above 80 watts. Whereas in PHP 'C' dry-out zone increases above 110 watts.

2] 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.

3] 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 these experimental setups we are conclude that at 50% filling of CLPHP give the optimum result.

A. 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.

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

Sr No	Parameter	First configuration	Second configuration	Third configuration
1	Evaporator Length (Le)	60mm	60mm	60mm
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