A Review on Thermal Performance Analysis of Close Loop Pulsating Heat Pipe

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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, rejection, 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 various literatures are reviewed to understand the working culture of Pulsating Heat Pipe. There are several studies are available based on the PHP. Some of them are focusing on the thermal resistance of PHP while some others are based on the heat carrying capacity improvement. Summary of all those studies is taken for further study

Key Words: *PHP, Thermal Resistance, HVAC, Heat Addition*

1.INTRODUCTION

In this paper the different work was proposed by the researcher for development in thermal performance of the pulsating heat pipe. Such as various parameters which affect the thermal performance of the closed loop pulsating heat pipe includes internal diameter of tube and filling ratio of working fluid in tube in the pulsating heat pipe improving the thermal performance [1], [3], [6], [12], [11], [18], [19]. Also some researcher has been studied for development of new design of pulsating heat pipe like varying channel diameter, total numbers of turns and filling ratio [14], [2], [7], some of them tested different configuration of Pulsating Heat Pipe for improving its performance [9], [10], [14], [15], and discussed about the factor affecting its performance like heat input and angle orientations [5], [8], [13]. From literature survey the working of PHP used for different working fluid like ethanol, methanol, acetone and R123 and device orientation [2], [4], [1], overall in this paper maximum research issued about the heat pipe were present as follows

2. EXPERIMENTAL STUDIES AND MATHEMATICAL MODELING

P. Charoen sawan et.al [1] investigated that the “Closed loop pulsating heat pipes Part A: parametric experimental investigations”. In their research 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). The number of turns in the evaporator is varied from 5 to 23. The working fluids employed are water, ethanol and R-123. The conclusion of their experimentation were, gravity has a great influence on the performance on the CLPHP, internal diameter must be specified with critical bond number within the limit, the performance can be increased by increasing the ID for a given temperature differential, thermal performance improves with increase in internal diameter.

Shi liu et al [2]; Their research named “Experimental study of flow patterns and improved configuration for pulsating heat pipe” have used two special configurations, 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. Optical visualization results indicated that there might exist three flow patterns, For a given geometry and an adequate fill ratio, the PHPs had the self-adjusting characteristic for the flow patterns to meet the demands of the increasing heat input. The thermal performance of the PHPs was examined over a range of working conditions. Comparing with the normal PHP with uniform diameter, either of the improved PHPs exhibited higher thermal performance.

B.Y.Tong.et.al. [3], Included that experimental studies on “Closed-loop pulsating heat pipe.” In this present work 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 start up period the working fluid oscillates with large amplitude but at steady state it circulates in the tubes. The direction of the working fluid flow is different for same set up and same experiment either clockwise or counterclockwise. In their search phenomenon of nucleation boiling, collapse of bubbles, formation of slug and propagation of flow inertia is being observed. It is found that of above experimentation is large amplitude oscillations occur form heat continuous circulation occurs. The fluid motion is continuous due to interplay between the driving and restoring forces also no permanent dry out at the heat receiving section occurs. When heat input increases the fluid circulation velocity is also increases.

Khandekar et al. [4] investigated the "Thermal performance of closed loops pulsating heat pipe at various heat input". In their study, there are 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. Three different working fluids viz. water, ethanol and R-123 were employed. The PHP was tested in vertical and horizontal orientation. The results strongly demonstrate the effect of input heat flux and volumetric filling ratio of the working fluid on the thermal performance of the device. 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. Also it was found from the experimental results that thermal efficiency of closed loop pulsating heat pipe with ethanol as working fluid increases first and then decreases.

P. Charoen sawan et.al [5] investigated the "Closed loop pulsating heat pipes Part B: visualization & semi- empirical modeling". In their study 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 00,300, 500, 700and 900 from the horizontal axis. The transparent CLPHPs were completely made of Pyrex glass tubes with Di = 2 mm. The evaporator section was heated by silicone oil, the inlet temperature of which was always maintained at 800 C. The mass flow rate was adjusted to maintain near isothermal boundary conditions. The condenser section was cooled by distilled water always maintained at 200 C. From the outlet temperature and mass flow rate of the coolant, the heat transfer could be calculated.

Brian Holley et al [6] have studied the "Analysis of pulsating heat pipe with capillary wick and varying channel diameter". They have a worked on Variation in channel diameter is investigated as a means of enhancing heat transfer in a pulsating heat pipe with capillary wick using the model presented here. The PHP assembly was made of high quality glass capillary tube with the outside diameter of 6.0 mm with the wall thickness of 2.0 mm. Thus the inside diameter of the capillary tube is 2.0 mm. The bending radius of the U bend in the evaporator section and the inverted U bend in the condensation section is 6.0 mm, forming eight snake-shaped PHP structure. The total height of the PHP is 200 mm with the total width of 90 mm. The height of the evaporator section is 56 mm while the condensation section has the height of 144 mm. In the evaporator section, the thermal load was provided by Ni–Cr thermic wire with a diameter of 0.4 mm (12 X/m) which was wrapped at intervals of 1.5 mm on the outer wall surface of the PHP. Because the evaporator section is well heat insulated. The heat received in the evaporator section is nearly totally dissipated to the condensation section. Due to the small heat transfer coefficient on the outer wall surface, the length of the condensation section is nearly two times of the evaporator section.

Jian et al [7] investigated the "Nonlinear analysis of temperature oscillation in close loop pulsating heat pipe". In their work the chaotic behavior of wall temperature oscillations in a closed-loop pulsating heat pipe was investigated using non-linear analyses on temperature data. The tested heat pipe, consisting of 5 turns, was made of copper capillary tube and had an internal diameter of 2 mm. Ethanol was selected as the working fluid with filling ratios (FR) of 30%, 50% and 70%. Wall temperature fluctuations were recorded under three different heating power inputs of 37, 60, and 87W. It was found that the fill ratio of working fluid as a percentage of evaporator volume is shown to have minimum effect on the performance of heat pipe with respect to the temperature difference when Ethanol are used as working fluids.

S.G. Khedkar et al [8] included that experimental studies on "Thermo-hydrodynamics of closed loop pulsating heat pipe" in pulsating heat pipes (PHPs), may be classified in a special category of heat pipes. However, it is different from the conventional heat pipe in the design and working principle. The basic structure of a closed loop PHP consists of a long capillary tube bent turn by turn and joined end to end, forming an elongated serpentine loop, No internal wick structure is required to assist the condensed working fluid to flow back to the evaporator. The tube is first evacuated and then filled partially with a working fluid. If the inner diameter of the capillary tube is small enough such that the working fluid will distribute itself along the tube length forming liquid slugs and vapor bubbles due to the effect of surface tension. The relative magnitude of sensible and latent heat portions and the overall thermal performance are dependent on the flow pattern existing inside the PHP.

S.Y. Nagvase et al [9]; in their study titled "Parameters Affecting the Functioning of Close Loop Pulsating Heat Pipe: A Review". They have explained that Pulsating Heat Pipe (PHP) is a passive two-phase heat transfer device for handling moderate to high heat fluxes typically suited for power electronics and similar applications. It usually consists of a small diameter tube, closed end-to-end in a loop, evacuated and then partially filled with a working fluid. The internal flow patterns in a PHP are a function of the applied heat flux. This includes internal tube diameter, applied heat flux and filling ratio. Additionally the numbers of turns and thermo-physical properties of working fluid also play a vital role in determining the thermal behavior. Apart from their paper is a literature review on pulsating heat pipe technology; work performed by Researchers. Finally, unresolved issues on the mechanism of PHP operation with different type of working fluids, validation techniques and applications are discuss Pulsating heat pipe is gaining more and more popularity, which due to their simple design, cost effectiveness and excellent thermal performance may find wide applications. Since their invention in the early nineties, so far they have found market niches in electronics equipment cooling.

R. R. Uday Kumar et al [10]; Included that experimental studies on "Effect of Design Parameters on Performance of

Closed Loop Pulsating Heat Pipe" Pulsating heat pipe (PHP) is a passive two-phase heat transfer device for handling moderate to high heat fluxes typically suited for power electronics and similar applications. It usually consists of a small diameter tube, closed end-to-end in a loop, evacuated and then partially filled with a working fluid. Heat transfer is through natural oscillations of the working fluid between the evaporator and condenser sections. In the present work, the experimental studies are carried out on a single loop PHP for the variation of applied heat flux, filling ratio and working fluids. The performance parameters of PHP like thermal resistance and heat transfer coefficient are would be evaluated for the above conditions. The experimental investigations are carried out on a single loop PHP. The effects of heat input, Working fluid and fill ratio on the performance of PHP are studied. The temperature difference between evaporator and condenser is lower for acetone compared to other working fluids. When heat input increases the thermal resistance will decreases and heat transfer coefficient will be increases. When heat input increases the fluid circulation velocity is also increases. Acetone is the most suitable working fluid for PHP operation when compared to other working fluid.

Pramod R. Pachghare et al [11]; in their experimental study on "Thermal Performance of Closed Loop Pulsating Heat Pipe Using Pure and Binary Working Fluids", the result shows that, the thermal resistance decreases more rapidly with the increase of the heating power from 20 to 60 W, whereas slowly decreases at input power above 60 W. Pure acetone gives best thermal performance in comparison with the other working fluids. The evaporator temperature of methanol is low in high power inputs. A PHP of water-methanol binary mixture gives good thermal performance over other working fluids. In all working fluids, pure water is having more thermal resistance whereas pure acetone is having lesser thermal resistance. So in this set-up, pure acetone gives best thermal performance in comparisons with the other pure and binary mixtures working fluid.

Roger R. Riehl et al [12]; investigated that the experimentally studies on "Characteristics of an Open Loop Pulsating Heat Pipe" Their paper presents an experimental investigation of an open loop pulsating heat pipe (OLPHP), while tests were conducted with different working fluids for the OLPHP operating at both vertical and horizontal orientations. The experimental results show that the system presented better performance when operating at horizontal orientation, as lower evaporation section temperatures were achieved. Regarding the working fluids used the system showed better performance when acetone was used on vertical orientation and methanol on horizontal orientation. From the experimental results, for filling ratio of 50 % and vertical orientation, it could be observed that acetone presented the best results. On the other way, water has presented the worse performance.

T.R. Mohod et al [13]; investigated the experimentally studies on "Design Parameters of Pulsating/Oscillating Heat Pipe: A Review". Their paper attempt theoretical and experimental investigation and scrutinized that internal diameter of tube and orientation numbers of turn's evaporator length, adiabatic length affect the performance of PHP/OHP. A filling ratio of 50% of its total volume is optimum. From the above literature review it can be conclude that the various design parameters affect the working performance of the pulsating heat pipe. The internal diameter of the tube effect the heat transfer rate if the internal diameter is greater or lesser according to the tube length i.e. No proportion occurs there will be effect of gravity and surface tension on the working of the PHP.The working fluid is as per the require condition and orientation of the PHP. The inclination angle also a vital effect on performance of the PHP, vertical PHP can work efficiently than the horizontal PHP; from the above literature review it is found that inclination angle from 70° to 90° is efficient performance. Number of meandering turns effect performance of PHP directly proportational to heat transfer flux.

S.G. Khedkar et al [14]; investigated that the experimentally studies on "Effect of Working Fluid on Thermal Performance of Closed Loop Pulsating Heat Pipe: A Review "This paper highlights the thermo-hydrodynamic characteristics of these devices. State of art indicates that's at least three thermo-mechanical boundary conditions have to be met for the device to function properly as pulsating heat pipe. This includes the internal tube diameter, the applied heat flux and amount of the working fluid in the system. Additionally the numbers of turns of the device and thermo-physical properties of the working fluid also play a vital role in determining the thermal behavior. Apart from this, paper is a literature review on pulsating heat pipe technology and work performed by researcher; it investigates experimental work performed on operating mechanisms of PHP, by using various working fluids. PHPs are highly attractive heat transfer elements, which due to their simple design, cost effectiveness and excellent thermal performance may find wide applications

Dharmapal A Baitule et al [15]; investigated that the experimentally studies on "Experimental Analysis Of Closed Loop Pulsating Heat Pipe With Variable Filling Ratio" In their work, transient and steady state experiments are conducted on a two turn closed loop PHP. Copper is used as the capillary tube material in the evaporator and condenser sections with inner diameter of 2 mm and outer diameter of 3 mm. The total length of the closed loop pulsating heat pipe is 1080 mm. The evaporator and condenser sections are 360 mm and 280 mm respectively. The experiments are conducted on vertical orientations for different heat loads varying from 10 W to 100 W in steps of 10 W. The PHP is tested on Ethanol, Methanol, Acetone and Water as working fluids for different fill ratios from 0% to 100% in steps of 20%. The performance parameters such as temperature difference between evaporator and condenser, 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 PHP are found to be better at a fill ratio of 60% for various heat input. 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 60% filling of PHP give the optimum result.

3. CONCLUSION

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

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