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Oscillating closed loop pulsating heat pipe: A Literature review

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***Abstract**: The experimental results on the thermal performance of close loop pulsating heat pipe is represented by many researchers. The CLPHP is made of copper capillary tube, having inner tube and outer tube are 1.78mm and 3mm respectively. In this experiment we are going to study the effect of inclination angleand working fluid on heat transfer performance of CLPHP .The performance is done with inclination angle of 0 (vertical), 30,45,60,75,and 90 (horizontal).The working fluid used as methanol for experiment filling ratio [FR]50%, 11 turns of copper capillary tube. The length of evaporator,condenser,and adiabatic section are 50mm of each. Silver metal coating on copper capillary tube in evaporator and condenser section*
***Keywords**: Pulsating heat pipe; Oscillating heat pipe;Heat transfer performance; Thermal resistance*

I. Introduction

The pulsating heat pipe (oscillating heat pipe) was first patented by a Japanese researcher named Akachiin the 1990s. The operation of the device is based on the principleof oscillation for the working fluid and phase change phenomenon in a capillary tube. Because of simple design,low cost,high thermal performance,and rapid response to high load ,PHP has been considered as one of the best technologies for electronic cooling ,the spacecraft thermal control system,heat exchanger,etcAs a new type of heat pipe, PHP showed great potential in the electronic cooler area. There are many factors that affect the heat transfer performance of PHPs, such as the orientation, filling ratio, heating patternand working fluids, and so on, that have been studied actively in recent years. . It was found that PHP can work an optimum filling ratio of 50%. According to previous studies,main thermo mechanical factors can be considered as the initial design factors influencing the PHP system .Those are as follows:

I. Heat pipe inclination,
II. Critical heat flux (heat transfer rate) of the heat pipe,
III. Number of turns,
IV. Working fluid and its thermo physical properties
V. Material,inner &outer diameter of PHP tube

II. Literature Review

1. Pramod R. Pachghare, Ashish M.Mahalle They conducted experiment onEffect of pure and binary fluids on closed loop pulsating heat pipe thermal Performance, to determine the effect of working fluid (binary or mixed) on closed loop pulsating heat pipe. This paper presents experimental results on thermal performance of close loop pulsating heat pipe using copper tube having internal diameter– 2.00mm, external diameter- 3.6mm, Material used is copper and working fluid used are Water, ethanol, acetone, Methanol and different binary mixtures. From the experiments the results shows that the thermal resistance decreases more rapidly with the increase of the heating power ranging from 20W to 60W,The conclusions from this experiment are 1. For above said working fluids of PHP, thermal resistance is decreases with the increasing heat inputs. The dry-out for the water-methanol, water-acetone and water-ethanol PHPs are at 85W, 80W and 90W heat input respectively, which is approximate the algebraic mean values of the boiling point of binary mixture. 2. Forhigh power inputs the evaporator temperature of methanol is low in. A PHP of water-methanol binary mixture gives good thermal performance over other working fluids. In this experiment result shows that the pure acetone gives best thermal performance in comparisons with the other pure and binary mixtures working fluid. No measurable difference has been recorded between the PHP running with pure and binary mixture working fluids, in terms of overall thermal resistance.

2. **Dharmapal A. Baitule and Pramod R. Pachghare** they are conducted experiment ontheir work on experimental analysis of closed loop pulsating heat pipe with variable filling ratio. 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. The different fill ratios are from 0% to 100% in steps of 20%.The experimental results shows the lower thermal resistance, heat transfer characteristics, and higher heat transfer coefficient of PHP are found to be better at a fill ratio of 60% for various heat input. The results from model are summarized as follows: 1.As there is increase in heat input the thermal resistance of closed loop pulsating heat pipe decrease. At the lower heat input (Q < 60 W) the thermal resistance is decreased slowly and at higher heat input (Q > 60 W) the difference is smaller. 2. The thermal resistances have the results of acetone<methanol<ethanol

3.SuchanaAkter Jahan, Mohammad Ali, Md.QuamrulIslamh They conducted experiment on the effect of inclination angle and working fluid on the heat transfer characteristics and performance of CLPHP. The performance has been inspected using two different working fluids of water and ethanol.The inclination angle of 0˚ (vertical), 30˚, 45˚, 60˚, 75˚ and 90˚ (horizontal). The experiment is conducted on a CLPHP made of copper capillary tube. The length of copper capillary tube is 148 cm and has 3.0 mm outer diameter and 2.0 mm inner diameter creating a total of 13 turns. The evaporator section total length is 39.5 cm and condenser section is 31.5 cm; while the rest is assumed to be adiabatic. The evaporator section is heated by electrical heat input and the condenser section is cooled by atmospheric air flow. Since a PHP is recognized as a two phase heat transfer device, for comparative studies it is operated as a double-phase system by filling it 70% with the working fluid. The results demonstrate the effect of the input heat flux, inclination angle and physiochemical properties of the working fluid on the thermal performance of the device.

The experiments being carried out for water and ethanol and for 6 different angular orientations of the heat pipe, provide a similar trend of thermal characteristics. In this research, the value of thermal resistance is considered as an indication of efficiency, i.e.The higher value of Rth refers to higher difference of temperature between evaporator and condenser section and eventually indicates a higher efficiency of the system.

4..**Pramod R. Pachghare, Ashish M.Mahalle** They are conducted experiment onThermo-hydrodynamics of closed loop pulsating heat pipe it has an experimental study The experimental result on the thermal performance of closed loop pulsating heat pipe (CLPHP) is presented. The CLPHP is made of copper capillary tubes, having inner and outer diameters of 2.0 mm and 3.6 mm respectively. The working fluids used are water, ethanol, methanol and acetone also binary mixture (1:1 by volume) of water-ethanol, water-methanol and water-acetone. For all experimentations, filling ratio (FR) 50%, two-turns and vertical bottom heat mode position was maintained. The lengths are selected as evaporator 42 mm, condenser 50 mm and adiabatic 170 mm. Based on the experimental study the conclusions are summarized as follows: Thermal performance is quantitatively contributing on boiling point and latent heat of vaporization of working fluid. In addition, dynamic viscosity and surface tension also play an important role to drive liquid slug against gravity in vertical position for circulation.

5. D. Manginia , M. Mameli a, A. Georgoulas a, L. Araneo c , S. Filippeschi b , M. Marengo,They are research on A pulsating heat pipe for space applications: Ground and microgravity experiments. inthis a novel concept of a hybrid Thermosyphon/Pulsating Heat Pipe with a diameter bigger than the capillary limit is tested both on ground and in hyper/micro gravity conditions during the 61st ESA Parabolic Flight Campaign. The device is filled with FC-72 50% vol. feeling ratio and it is made of an aluminum tube with I.D. 3 mm. The tube bent into a planar serpentine with five curves at the evaporator zone, while a transparent section closes the loop, fluid flow visualizations is in the condenser zone. Five heaters are mounted alternatively in the branches just above the curves at the evaporator zone, provide an asymmetrical heating thus promoting the fluid flow circulation in a preferential direction.

The device has been tested at different positions (vertical and horizontal) and at different heat power input levels (from 10 W to 160 W). Ground tests show that effectively the device works as a thermosyphon when gravity assisted: in vertical position the device can reach an equivalent thermal resistance of 0.1 K/W with heat fluxes up to 17 W/cm2 . In horizontal position the fluid motion is absent and the device works as a pure thermal conductive medium. The parabolic flight tests point out a PHP working mode: during the micro-gravity period, the sudden absence of buoyancy force activates an oscillating slug plug flow regime, typical of the PHP operation, allowing the device to work also in the horizontal position n. According to the authors' best knowledge, this is the first attempt in literature that such a hybrid device is tested.

6. HarshalGamit, **VinayakMore,**They are conducted experiment on investigation of pulsating heat pipe. Pulsating heat pipes are new member to the family of heat pipes used for higher heat removal. Various experiments have been carried out in order to check the effect of filling ratio and input heat flux on the performance of (CLPHP). Working fluid used in this experiment is water. Inner diameter of the copper tube is 2.15mm.Natural convection in condenser section. Filling ratio taken are as as 40%, 50% and 60%. Heat input ranges from 10W, 20W, 30W, 40W and 50W. The results indicated better system performance with lower level of filling ratio and at higher input.

7. **Roshan D Bhagat, K.M. Watt,**They are conducted experiment based on Performance investigation of closed loop pulsating heat pipe with acetone as working fluid. Copper has been selected as material for heat pipe due to compatibility of copper with acetone as working fluid. Filling ratio of the working fluid effects on the performance closed loop pulsating heat pipe. Filling ratio of 30-75 % provides the best result hence 60 % filling ratio has been selected for this filing ratio the thermal performance of closed loop pulsating heat pipe with acetone as working fluid is investigated. This paper conclude that the thermal resistance of closed loop pulsating heat pipe decreases with increase in the heat input for both methanol and acetone hence the thermal performance of closed loop pulsating heat pipe increases with increase in the heat input.

8. Xiaoyu cui,ZiqianQiu,JianhuaWenge, Zhihua Li,In this paper, an experimental study is presented on the thermal resistance characteristics of closed loop pulsating heat pipes (CLPHPs) with methanol-based binary mixtures. The working fluids were methanol mixed with deionised water, acetone and ethanol. The volume mixing ratios used were 2:1, 4:1 and 7:1, and the heating power ranged from 10W to 100W with filling ratios of 45%, 62%, 70% and 90%. The results showed that adding other working fluids to methanol could change the thermal resistance characteristics of a PHP. At a low filling ratio (45%), adding water to methanol could prevent dry-out at a high heating power; when ethanol was added to methanol, the thermal resistance of the CLPHP was between that with pure methanol and ethanol; when acetone was added, the thermal resistance of the CLPHP was slightly lower than that with pure methanol and acetone. At a high filling ratio (62%, 70%, 90%),It can be inferred that the heat transfer performances of CLPHPs with methanol-based binary mixtures are related to the thermal-physical properties of the working fluids, vapor–liquid phase transition properties, molecular interactions and the additional resistance to mass transfer.

9. Mauro Mamelia,Marco Marengo a, Sameer Khandekar. In this research on Local heat transfer measurement and thermo-fluid characterization of a pulsating heat pipe. A compact CLPHP which is filled with ethanol with 65% v/v, adiabatic section made of four transparent glass tubes forming the and connected with copper U-turns in the evaporator and condenser sections respectively, and is designed to perform comprehensive thermal-hydraulic performance investigation. Local heat transfer coefficient is estimated by measurement of tube wall and internal fluid temperatures in the evaporator section. At the same time fluid pressure oscillations are recorded together with the corresponding flow patterns. The thermal performances are measured for different heat input levels and global orientation of the device with respect to gravity. One exploratory test is also done with azeotropic mixture of ethanol and water. Results show that a stable device operation is achieved (i.e. evaporator wall temperatures can reach a pseudo-steady-state) only when a circulating flow mode is established superimposed on local pulsating flow. The heat transfer performance strongly depends on the heat input level and the inclination angle, which, in turn, also affect the ensuing flow pattern.

The spectral analysis of the pressure signal reveals that even during the stable performance regimes, characteristic fluid oscillation frequencies are not uniquely recognizable. Equivalent thermal conductivities of the order of 10e15 times that of pure copper are achieved. Due to small number of turns horizontal mode operation is not feasible. Preliminary results indicate that filling azeotropic mixture of ethanol and water as working fluid does not alter the thermal performance as compared to pure ethanol case. The input heat power provided to the evaporator zone is one of the key experimental control parameters. Khandekar showed that the CLPHP may work in different modes (oscillation/ circulation) depending on the heat input level and that different flow patterns occur when the heat input is increased. In order to characterize the response to the start-up heat flux, a series of experiments are performed and a common trend has been recognized: for low initial heat input levels (from 0 to 30 W, corresponding to a radial heat flux between 0 and 3.9 W/cm2) the device behavior is mainly unstable and it cannot reach a pseudo steady-state even if the heat input is then increased during the experiments; for higher initial heat input levels (from 40 W corresponding to a radial heat flux of 5.2 W/cm2) the device behavior is much more stable and a pseudo-steady-state of its operation can indeed be reached at each higher heat input level thereafter

10. V. K. Karthikeyan, K. Ramachandran,B. C. Pillai, A. Brusly Solom, They are conducted experiment onUnderstanding thermo-fluidic characteristics of a glass tube closed loop pulsating heat pipe: flow patterns and fluid oscillations. An experimental program has been carried out to understand the thermo-fluidic characterization of deionized (DI) water charged closed loop pulsating heat pipe (CLPHP) with flow patterns and fluid oscillations. The CLPHP is examined under vertical and horizontal heating modes with varying heat power. The flow patterns along with fluid oscillations are correlated with thermal performance of the CLPHP. The CLPHP was made up of Pyrex glass capillary tube with total height of 200 mm, width of 140 mm with 5 turns. The inner and outer diameters of the glass tubes were 2.5 and 6 mm respectively. The heights of evaporator and condenser sections were 50 and 150 mm respectively.

The height of the condenser section was equal to three times of the evaporator section due to small amount of heat transfer coefficient on the outer wall surface of the glass tubee. The filling ratio was 50 % of the total volume of the glass tube. The visual experimental investigation is carried out to understand the thermal-fluid behaviour of a CLPHP. The effect of heat power, heating mode and working fluid on the thermal performance of the device are investigated. The flow patterns and fluid oscillations are captured while in operation. The thermal resistance and effective thermal conductivity are measured in a CLPHP.

III. Conclusion

From the discussion, we have analyzed the following results:

1. The heat transfer capacity with pure copper material and various working fluid investigated by different authors. ButHeat transfer capacity of copper withmetal coating has not investigate still. To enhance heat exchange capacity of PHP another high thermal conductive metal coating is needed.

2. The working fluid also play an important role in heat transfer capacity. The different working fluid will be used to investigate thermal performance. Thermal characteristics and performance is also depends upon internal and outer diameter, material filling ratio, specific heat and sensible heat. The investigations has needed on this parameters also.

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