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Influence of Working Fluids on Thermal Performance of Flat Plate Oscillating Heat Pipe

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Abstract: With development of higher electronic devices, there is a need for better thermal management. The heat output of these devices can potentially exceed the heat transfer capabilities of current heat pipe designs. Oscillating heat pipes (OHPS) have high heat spreading performance and are capable of removing higher heat fluxes. OHP is superior compared to traditional heat pipes and can be used to solve the future cooling problems. This study presents the thermal performance of Flat plate oscillating heat pipe (OHP) using different working fluids with mini channels. The FP-OHP were fabricated with the channels of square cross section which had hydraulic diameters of 2 mm in mini channels. The performance of the FP-OHP will be measured and analysed by keeping 50% filling ratio, vertical position and varying input power and with different working fluids.

Keywords: Flat plate Oscillating heat pipe, Thermal performance, Working fluids.

I. INTRODUCTION

A. What Is Heat Pipe?

The heat pipe is a passive heat transfer device that effectively utilizes evaporation and condensation to transfer heat over a long distance. A heat pipe consists of a container charged with a working fluid. This sealed container is divided into three sections: Evaporator where heat is added, Adiabatic section where no heat transfer exists, and condenser section heat is rejected. The heat pipe is evacuated and then filled with the working fluid. When heat is supplied to the evaporator section, heat transfer takes place from container walls and heat the working fluid inside. The working fluid vaporizes and vapour is generated in the evaporator section when the saturation temperature corresponding to the local saturation pressure is reached. The temperature of the evaporator section is more than that of condenser section. The saturation pressure in the evaporator is higher than the saturation pressure corresponding to the condensation temperature in the condenser. Vapor flow from the evaporator section to the condenser section is mainly because of the pressure difference caused due to temperature difference between the evaporator and condenser. The condensate in the condenser is pumped back by the Electrostatic force, gravitational force, centrifugal force & capillary forces. Because of this the heat is transported from the evaporator to the condenser.

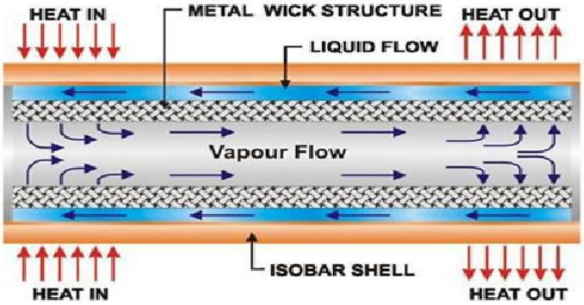

Fig 1: A Basic Heat Pipe Structure

A Oscillating Heat pipe: Oscillating heat pipes are also known as pulsating heat pipes (PHP) & are a relatively new development in the field of heat pipe technology. An OHP is a meandering tube consist of a serpentine channel having capillary dimension which is cooled and heated at various points along its length. Operation of Oscillating heat pipe is mainly based on the phase change phenomena in a capillary tube and the principle of oscillation for the working fluid. For vapor & liquid plugs to exist the diameter of the tube must be small enough. Initially, the oscillating Heat Pipe is evacuated and then it is partially filled with the working fluid. The liquid slugs interspersed with vapor bubbles are formed due to the Effects from surface tension.

II. LITERATURE REVIEW

Harshal Gamit et al. (2015) had carried out experimental investigation on CLPHP made up of copper tube with 2.5mm inner diameter with water as working fluid. Experiment was conducted with different filling ratio & Heat inputs. System performs better with Lower FR for same input Heat flux. As Heat input increases, thermal resistance decreases due to chaotic fluid movement. For FR=40% Chaotic fluid movement is observed with condenser temperature. As Heat input is increased with the same FR, larger fluctuations are observed. This is also observed for FR=60% but the amplitude is lower as compared to 40% and 50% FR [2]

K.H.Chien, Y.R.Chen, Y.T.Lin, C.C.Wang, K.S.Yang (2011) had Experimentally investigate Thermal performance of FPOHP. Two Heat pipes were made of copper capillary tubes with uniform & Non-uniform CL-PHPs, and working fluid as Distilled water with filling ratio's 40%, 50%, 60%, 70% respectively and inclination angle of 0°, 30°,60° & 90°. And found that for increase in inclination angles Thermal resistance decreases with rise of inclinations due to gravity effect. Uniform channel CLPHP shows poor heat transfer performance at horizontal orientation and to improve this non-uniform CLPHP is used [3].

Samad Jafarmadar, Nazli Azizinia (2016) Had investigated effects of nanoparticle & volume concentration on the flow characteristics, heat transfer & entropy generation of PHPs with different Nano-fluids including Al2O3 ,CuO and silver Nano-fluid as working fluids. Conclusion made that silver Nano-fluids has highest rate of entropy generation & irreversibility because of delay in oscillation & bubble generation. Heat transfer rate remains unchanged by increasing volume fraction of nanoparticles. Reasonable particle volume fraction is about 0.5-1% [4].

Himel Barua et al. (2013) Had investigated Heat pipe at different Heat input, filling ratio & fluid as water and Ethanol. For low Heat water is better working fluid than ethanol at wide range of F.R. But at high heat input (more than 70W) Both working fluid shows nearly same thermal resistance. For water optimum heat transfer is obtain at nearly 30% filling ratio. For Ethanol best performance is obtained at nearly high filling ratio beyond 50% [5]

V.M.Patel et al.(2017) had experimentally investigated influence of eleven working fluids mainly Deionized water, Ethanol, Methanol, Acetone, water based mixture (1:1) of acetone , methanol, ethanol as binary fluids & sodium dodecyl Sulphate is used as surfactant with 30, 45, 60, 100PPM. With FR=50% and heat input varied from 10 to 110W. CLPHP is failed to start up pulsation below 20W heat input for all working fluids. Start-up heat flux is observed lower for acetone compared to all other fluids. Water has highest start up heat input. Addition of other pure fluids or surfactant in water reduces surface tension & hence reduces start up heat flux compared to pure water. Among Base fluid acetone gives better performance & among Binary fluids water-acetone gives better performance [6]

X. Cui et al. (2016) had experimentally studied thermal resistance characteristics of CLHPs using methanol based binary mixture with volume mixing ratios 2:1, 4:1 & 7:1. Heat power is varied from 10W to 100W with filling ratio 45%, 62%, 70% & 90%. For filling ratio of 45% adding water to methanol can delay dryout and thermal resistance of CLPHP with methanol-water mixture is lower than other. Adding ethanol & acetone to methanol cannot effectively improve thermal performance. But at high filling ratio addition of water, ethanol & acetone cannot give effective heat transfer performance as compared to low filling ratio (45%) [7]

S. Shi et al. (2016) had experimentally investigated Heat transfer performance of PHP with ethanol-water , ethanol-methanol & ethanol-acetone with mixing ratio of ethanol based mixed working fluids as 2:1 & 4:1, volume filling ratio ranges from 45% to 90% and heat input is varied from 10W to 100W.Experimental results with 2:1 mixing ratio heat transfer performance of PHP with ethanol-water is better than other working fluids. At filling ratio of 45% and 50% PHP with ethanol-acetone shows better performance among all [8]

J.Qu H. Wu et al. (2011) studied thermal performance of OHP with SiO2-water & Al2O3 –water Nano fluids with mass concentrations, 0-0.6wt% for silica Nano fluids, 0-1.2wt% for alumina Nano fluids and volume filling ratio of 50% for alumina Nano fluids.

They found that for OHP with alumina Nano fluids there existed an optimal concentration of 0.9wt% at which reductions in over thermal resistance of 0.057°C/W and evaporator wall temperature of 5.6°C. For OHP with silica Nano fluids overall thermal resistance and evaporator wall temperature increased with increase in mass concentration of silica Nano particles [9]

L. M. Poplaski et al. (2017) presented 2-D laminar, steady, compressible heat pipe numerical model to simulate the operation of a conventional cylindrical heat pipe charged with Nano fluid. Nano particle concentration have greatest effect on fluid thermal conductivity and thermal resistance. Increase in nanoparticle concentration of Nano fluid lowered the total thermal resistance of heat pipe to an optimal volume concentration corresponding to capillary limit and was 25% vol. for both Al2O3 & TiO2, and 35% for CuO [10]

III. EXPERIMENT WORK

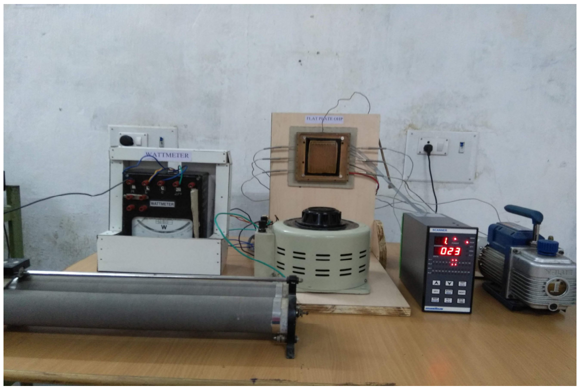

Fig 4. Experimental Setup

The setup mainly consists following components

1) *Copper Plate:* Thickness=10mm
2) *Condenser Block:* It is made up of copper plate having 8mm thickness, 30mm width and 70mm length. And having arrangement for water inlet and outlet.
3) *Evaporator Block:* It is fabricated using cooper block having same dimension as cooling block and access to locate cartridge heater
4) *Variac:* Variac has specification 3F, 300V, 60 Hz will be used for power supply.
5) *Glass Plate:* It is used to seal the plate airtight and of having 3mm thickness.
6) *Temperature Scanner:* It is multi-channel (6-channel) temperature indicator.
7) *Temperature Sensors:* It is k-type thermocouple sensors (7 No's) can sense temperature of the range - 200^0C to 1200^0C.
8) Cartridge heater (230V/100W): 1 No. of heaters are used, having dimension of 6mm dia. and 50mm length.
9) Vacuum Pump
10) Submersible Pump
11) Pressure Gauge

IV. RESULT AND DISCUSSION

Thermal resistance of an OHP can be calculated as follows:

$$R_{TH} = (T_E - T_C) / Q.$$

Where Q is the Heating power and T_E & T_C are the temperature of the evaporation section and condenser section at steady state respectively, which were obtained by averaging the temperature recorded by thermocouples 1-2 and 5-6 respectively.

$$T_E = (T_1 - T_2) / 2.$$

$$T_C = (T_5 - T_6) / 2.$$

TABLE I

Thermal resistance of different fluids versus heat input.

Heat Input(Q)	$R_{th(DI\ water)}$	$R_{th(ethanol)}$	$R_{th(methanol)}$	$R_{th(Acetone)}$
20	0.84	0.725	0.6	0.5
30	0.63	0.584	0.517	0.434
40	0.56	0.525	0.462	0.412
50	0.52	0.47	0.46	0.41
60	0.49	0.458	0.441	0.408
70	0.45	0.428	0.4	0.371
80	0.4	0.368	0.35	0.325
90	0.38	0.345	0.328	0.312
100	0.35	0.335	0.32	0.29

A. Sample Calculation of Thermal resistance of working fluid

The calculation of Thermal resistance of OHP is carried out according to following procedure.
From the Table of Thermal resistance of DI water for 30-Watt heat load sample calculations are as follows:
Evaporator Temperature: $T_1 = 44^0$C, $T_2 = 48^0$C.
Condenser Temperature: $T_5 = 25\ ^0$C, $T_6 = 28^0$C.

1) Mean evaporator Temperature: $T_e = (T_1 + T_2)/2 = (44 + 48)/2 = 46\ ^0$C.
2) Mean condenser Temperature: $T_c = (T_5 + T_6)/2 = (26 + 28)/2 = 27\ ^0$C.
3) Thermal Resistance: $R_{th} = (T_e + T_c)/ Q$ Where Q = Heat supplied in Watts.
$R_{th} = (46 + 27)/ 30. = 0.634\ ^0$C/ Watt.

B. Charts for Thermal Resistance verses Heat Input

Generally, the performance of OHP is measured in terms of Thermal resistance. Lower the thermal resistance indicates better performance of OHP. The OHP is been tested for different working fluids using DI water, Ethanol, Methanol, Acetone. Keeping same filling ratio as 50% and considering vertical position.

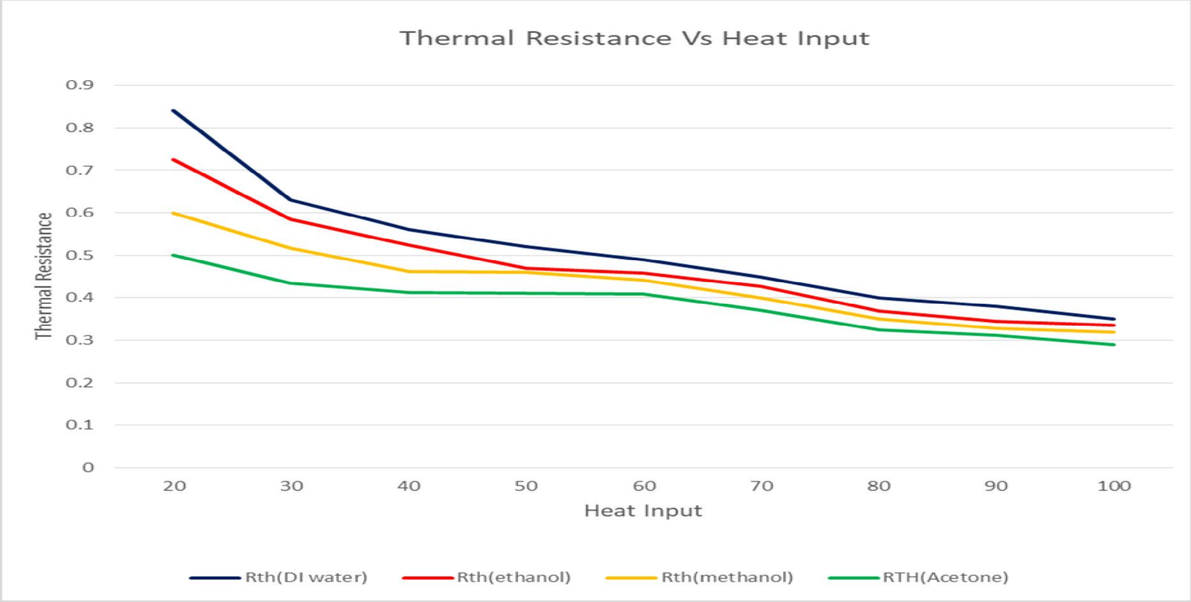

Fig 5: Thermal Resistance verses Heat input for different fluids.

V. CONCLUSION

Thermal performance increases with decreases in the thermal resistance, results in higher heat transfer rate from evaporator to condenser section. Thermal resistance is found to be optimum and lowest for acetone as compared to all fluids. When Heat input is maintained constant the thermal resistance is proportional to temperature difference between evaporator and condenser. When condenser temperature is fixed at specific value, a lower thermal yield a lower evaporator temperature and an excellent thermal performance.

Figure 5 shows effect of input power on thermal resistance of FPOHP for all working fluids thermal resistance decreases with increase in input power because of increased heat transfer between heat source and FPOHP from more active pulsating motion in channels. At Lower heat input prediction of thermal resistance is based on pure conduction and depends on properties of working fluids. Thermal resistance is observed highest for DI water and Lowest for acetone where as it falls in between for methanol and ethanol. Increase in heat input advocates influencing parameters which results to increase liquid vapor pulsation in FPOHP. Lowest physical properties of fluid make acetone suitable fluid for efficient thermal performance of FPOHP as compared to other fluids
Based on the results, the following conclusions are drawn:

A. The performance of FPOHP improves at a higher heat load.
B. Thermal resistance decreases with increases in heat input irrespective of different working fluids.
C. Acetone gives better performance of FPOHP compared to methanol, ethanol and DI water as working fluids.

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