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Uncertainty Analysis of Flat Plate Oscillating Heat Pipe with different Working Fluids

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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. The FP-OHP was 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 analyzed by varying input power with fixed filling ratio as 50% and keeping setup in vertical position using different working fluids. And uncertainty analysis is done based on this performance.*

Key Words*: *Flat plate oscillating heat pipe, Working Fluids, Thermal performance, Uncertainty analysis.

1. INTRODUCTION:

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 consists 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 vapour & 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 vapour bubbles are formed due to the Effects from surface tension.

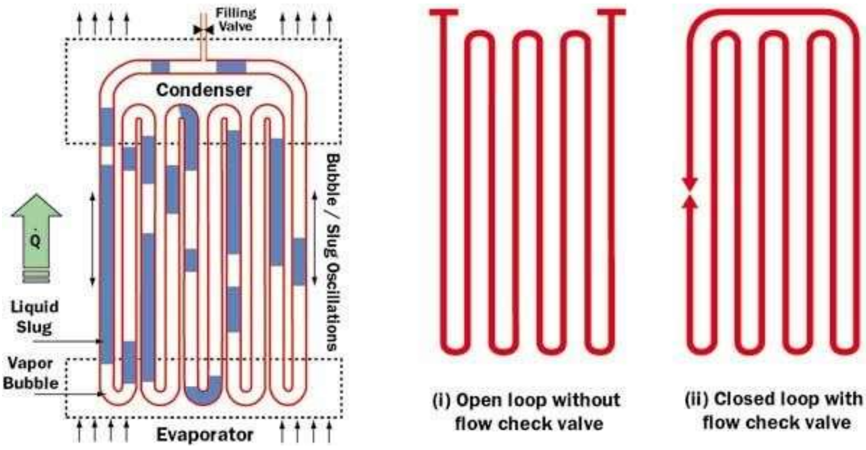

Fig-1: Oscillating heat pipe

Working principle of closed loop pulsating heat pipe.

Akachi and Polasek described the basic principle of an OHP such that: “When high temperature is supplies to the one end of the bundle of turns of the capillary tube the working fluid inside starts evaporating and the vapour pressure increases, due to which the bubbles are developed in the evaporator zone. This pushes the liquid column toward the condenser which has low temperature. Due to condensation taking place at the low temperature end there is increase the pressure difference between the two ends.

Because of the interconnection of the tubes, motion of liquid slugs & vapour bubbles at one section of the tube along the condenser also cause the motion of slugs & bubbles in the next section toward the evaporator (high temperature end), which works as a restoring force. The Interplay between the restoring force & the driving force leads to cause oscillation of the vapour bubble & liquid slugs in the axial direction. The amplitude and the frequency of the oscillation are expected to be dependent on the mass fraction and shear flow of the liquid in the tube". Heat is transferred through sensible heat transported by the liquid slugs & latent heat of the vapour.

2. EXPERIMENTAL SETUP:

Layout of experimental setup is shown in fig. 2 and experimental setup is shown in Fig. 3. It consists of a test section, temperature scanner, vacuum pump, wattmeter, rheostat, cooling water tank. The test section consists of an evaporator section, an adiabatic section and condenser section. Evaporator block is fabricated using copper block have 8mm thickness,30mm width and 70 mm length & has 1 hole for inserting cartridge heater of 6mm diameter and 50mm length. Each cartridge heater has the capacity of the 100W.The copper is selected due to its high thermal conductivity and good machinability properties. The heat loss from evaporator & condenser blocks to back side is prevented by providing asbestos sheet. Condenser block has same dimension as that of evaporator section. Test section also consists Flat plate oscillating heat pipe made up of copper plate having thickness of 10mm. Variac with specification 3F, 300V, 60Hz will be used for power supply. Masibus Temperature scanner is multiple channel temperature indicator having accuracy of 1^0C.k-type thermocouple sensors are used to sense temperature of the range $-200\ ^0C$ to $1200\ ^0C$. Single stage vacuum pump having Ultimate vacuum capacity of 150 microns is used to create vacuum.

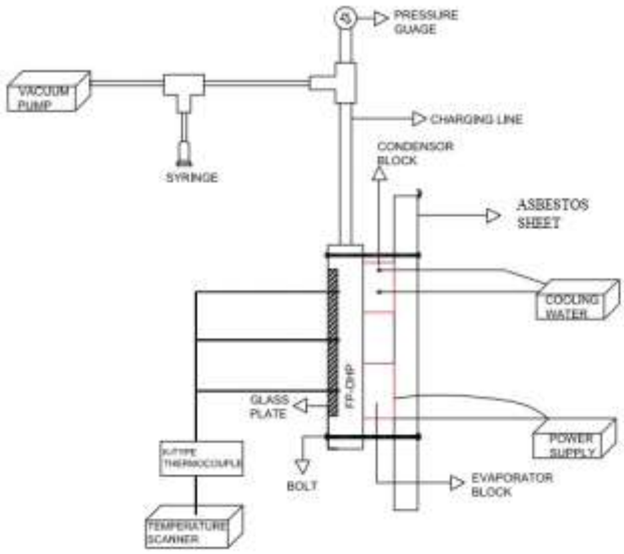

Fig-2 layout of Experimental setup

Fig-3 Experimental Setup

3. EXPERIMENTAL PROCEDURE:

The experimental setup will be prepared by following steps:

- The copper plate is fabricated to make the square cross section channel of 2x2 mm^2 and to drill 6 holes on the side of the plate for temperature measurement access.
- 2mm dia. hole is drilled at the upper end of the plate to insert the charging section.
- The temperature sensors are inserted in the plate and heaters are inserted in to the block.
- Charging section is made up of copper capillary tube. Syringe is used for filling working fluid in heat pipe.
- Temperature of evaporator section at different point will be recorded as T_1, T_2 and similarly for condenser as T_3, T_4.

3.1 Thermal resistance:

Thermal resistance of an OHP can be calculated as follows:

$$R_{th} = \frac{T_E - T_C}{Q}$$

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 3-4 respectively.

$$T_E = \frac{T_1 - T_2}{2}, \quad T_C = \frac{T_3 - T_4}{2}$$

3.2 Uncertainty analysis:

Yu Zhou, Xiaoyu cui, Jinhua weng, Experimental investigated the Heat transfer performance of an oscillating heat pipe with graphene Nano fluids [11]. The uncertainty analysis is calculated as follows:

- Uncertainty of the Heating power: Equipment's used in Heating test have an accuracy of 1%.

$$\frac{\delta Q}{Q} = \sqrt{\left(\frac{\delta V}{V}\right)^2 + \left(\frac{\delta I}{I}\right)^2}$$

- Uncertainty of the Thermal Resistance: The calibrated accuracy of the thermal resistance is 1 ^{0}C. Thus, the absolute uncertainty for the temperature measurement is:

$$\delta Te = \delta Tc = \delta T$$

- The maximum uncertainty of the thermal resistance was calculated as:

$$\left(\frac{\delta R}{R}\right)_{max} = \sqrt{\left(\frac{\delta Te}{Te - Tc}\right)^2 + \left(\frac{\delta Tc}{Te - Tc}\right)^2 + \left(\frac{\delta Q}{Q}\right)^2}$$

$$\left(\frac{\delta R}{R}\right)_{max} = \sqrt{2\left(\frac{\delta Te}{Te - Tc}\right)^2 + \left(\frac{\delta Q}{Q}\right)^2}$$

3. RESULT AND DISCUSSION:

The results obtained experimentally are discussed in this section. The influence of different working fluids on the thermal performance of FP-OHP is analyzed. Vertical bottom Evaporator position is considered for FP-OHP. Heat is supplied in the range of 10-100W. Uncertainty analysis is carried out.

3.1 Thermal performance of FP-OHP:

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. 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 yields a lower evaporator temperature and an excellent thermal performance.

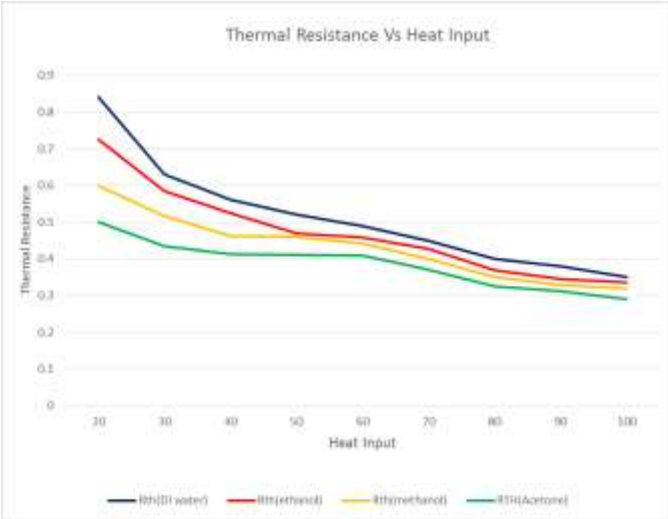

Fig-4 Thermal resistance versus heat input for different fluids.

Fig.4 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.

3.2 Uncertainty analysis for different working fluids:

Yu Zhou, Xiaoyu cui, Jinhua weng, Experimental investigated the Heat transfer performance of an oscillating heat pipe with graphene Nano fluids [11]. The sample calculation for uncertainty analysis for acetone fluid is calculated as follows:

- Uncertainty of the Heating power: Equipment's used in Heating test have an accuracy of 1%. Considering Acetone, for a Heating power of 20W measured voltage is 60V & current is 0.33A. Thus, the uncertainty of the heating power was calculated as:

$$\frac{\delta Q}{Q} = \sqrt{\left(\frac{\delta U}{U}\right)^2 + \left(\frac{\delta I}{I}\right)^2}$$

$$\frac{\delta Q}{Q} = \sqrt{\left(\frac{1\% * 250}{60}\right)^2 + \left(\frac{1\% * 1}{0.33}\right)^2}$$

= 5.17% = 0.0517

- Uncertainty of the Thermal Resistance: The calibrated accuracy of the thermal resistance is 1 ^{0}C. Thus, the absolute uncertainty for the temperature measurement is

$$\delta Te = \delta Tc = \delta T = \sqrt{1^2} = 1°C$$

For Acetone as working fluid Heating power at 20W, the minimum temperature difference between the evaporation section and the condensation section was $(Te - Tc)_{min} = 9.5^0$C.

$$\left(\frac{\delta R}{R}\right)_{max} = \sqrt{\left(\frac{\delta Te}{Te - Tc}\right)^2 + \left(\frac{\delta Tc}{Te - Tc}\right)^2 + \left(\frac{\delta Q}{Q}\right)^2}$$

$$\left(\frac{\delta R}{R}\right)_{max} = \sqrt{2\left(\frac{\delta Te}{Te - Tc}\right)^2 + \left(\frac{\delta Q}{Q}\right)^2}$$

$$\left(\frac{\delta R}{R}\right)_{max} = \sqrt{\left(\frac{1}{9.5}\right)^2 + (0.0517)^2}$$

$$\left(\frac{\delta R}{R}\right)_{max} = 15.7\%$$

Thus the maximum uncertainty of the thermal resistance was calculated as 15.7%. Similarly, uncertainty is calculated for all working fluids. Observation table is shown below:

Observation Table 1: Uncertainty analysis for different working fluids:

Heat Input(Q)	$(\frac{\delta R}{R})$ Acetone	$(\frac{\delta R}{R})$ Methanol	$(\frac{\delta R}{R})$ Ethanol	$(\frac{\delta R}{R})$ DI water
20	15.7%	12.4%	10.57%	9.7%
30	11.2%	9.5%	8.52%	7.91%
40	8.8%	7.92%	7.04%	6.62%
50	7.09%	6.37%	6.24%	5.79%
60	7.03%	5.51%	5.32%	4.89%
70	5.56%	5.18%	4.86%	4.57%
80	5.53%	5.14%	4.81%	4.53%
90	5.14%	4.89%	4.67%	4.27%
100	4.97%	4.53%	4.33%	4.16%

Uncertainty of thermal resistance mainly depends upon the difference the difference between evaporator temperature & condenser temperature and calibrated accuracy of instrument used. The $(T_e - T_c)$ found to be minimum for acetone fluid as compared to other fluids and also it is found to be lowest at low heat input. Hence uncertainty is maximum at low heat input and for acetone as working fluid as compared to other working fluids.

4. CONCLUSIONS:

The aim of this paper is to experimentally investigate the thermal performance of a FP-OHP which are greatly influenced by working fluids. DI water, ethanol, methanol, acetone as working fluids. The conclusions drawn for thermal performance of FP-OHP are as follows:

- The performance of FPOHP improves at a higher heat load.
- Thermal resistance decreases with increases in heat input irrespective of different working fluids.
- Acetone gives better performance of FPOHP compared to methanol, ethanol and DI water as working fluids.
- As heat input increases the uncertainty goes on decreases. Uncertainty is maximum at low heat input and for acetone as working fluid as compared to ethanol, methanol and DI water.

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