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Effect of Working Fluid, Heat Input and Filling Ratio's On Performance of Closed Loop Pulsating Heat Pipe

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ABSTRACT

Semiconductors are the main source for rapid response of electronics components. Thermal loads are responsible for serious damage of electronic components, which causes data loss. In order to improve the thermal management of electronic components, study on novel cooling systems for modern electronics is taking dominant importance. A new closed loop pulsating heat pipe (CLPHP) system has been proposed in this study.An experimental investigation on various filling ratio, heat input and time duration using CLPHP system for two working fluids (Ethanol and Acetone) was conducted using a copper tube of 2.8 mm diameter and 210 mm length with 3 bents. The experimental results showed compared to acetone, ethanol has given the minimum start up power and minimum thermal resistance for 50% filling ratio. The pulsation of Ethanol started dominating above 70 W of heat input for all the filling ratios. The temperature and thermal resistance were found lesser and a noticeable increment in heat transfer coefficient for filling ratio of 50% at the same heat input. For acetone, it is found that 50W is the optimal heat input for pulsations to start and sustain in all the filling ratios, but gave the better result in terms of lower temperature, thermal resistance and higher heat transfer coefficient for filling ratio of 60%.

Key Words: *PHP-Pulsating Heat Pipes, CLPHP-Closed Loop Pulsating Heat Pipes, Acetone, Ethanol, Filling ratio*

1. INTRODUCTION

Modern trends in thermal management of electronics components are very challenging and the limits are being compressed in every aspect like (a) reduced thermal resistance, (b) high heat transference capability, (c) higher heat flux, (d) long term reliability, and (e) low cost. These requirements pose to develop new device [1]. Under such stringent regulations, neoteric cooling, i.e. development of phase change techniques such as pool boiling, jet impingement cooling and more recently mini/micro channel flow boiling concepts have been addressed [2]. Out of many methods, heat pipes in various configurations and designs have played a major role in improving heat transfer of many electronics appliances in present days [3]. Pulsating Heat Pipes are thermal energy absorbing and transferring device best suited for electronics chips. Pulsating or closed looped type heat pipes (CLPHP's) is proposed and patented by Akachi [4] in later 1990. These are highly effective device for transmitting heat at high rates over significant distances with small end to end temperature drops, providing excellent flexibility in control and transport of high heat rates at various temperature levels, constructional simplicity, and easy control which operate without external power [5]. CLHP are "passive energy conversion devices" that transmits heat energy with the newer technology over other cooling techniques [6]. The working of heat pipe is based on the principle of oscillation of working fluid and a phase change phenomena by capillary effect [7]. CLHP consists of smaller diameter tube to provide capillary effect serpentine and connected end to end to form closed loop and the arrangement is as shown in figure 1. The vapor plugs and liquid slugs are formed as a result of capillary action [8].

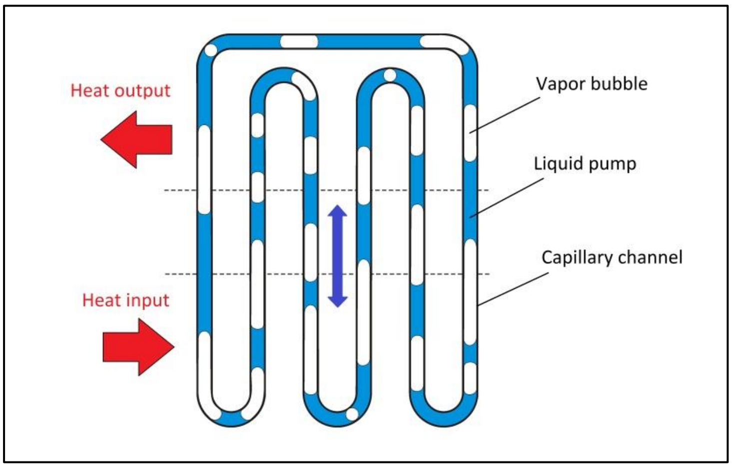


Figure1.1:Closed loop arrangement of capillary tube

The liquid slug and vapor bubblemovement is caused by the thermally induced pressure pulsations inside the device and no external mechanical power is required. The operating pressure inside the heat pipe depends on the type of fluid and operating temperature. Heat is transferred from evaporation section to the condenser section through pulsation of the working fluid in the axial direction of the tube which helps in providing simple construction with less weight. The effect of surface tension plays major role in dynamics of PHPs because of small diameter tube and enables successful operation in a microgravity environment without external power source.

2. LITERATURE

In 1963, Los Alamos physicist "George Grover" demonstrated heat transfer device working on capillary effect, for which he was patented and popularly called as inventor of het pipe. A mathematical model of steady-state loop heat pipe was developed which was able to predict the decreasing length of the condenser two-phase zone under the constant conductance mode caused by the volume expansion of the liquid and compared with experimental results and found satisfactory results [9]. Series of experiments was conducted on customized miniature loop heat pipes used for cooling of electronics with four horizontal and vertical tubes having 5 mm diameter and 29 mm length under various sink temperatures. The steady-state operating characteristics were found similar for all orientations except the orientation where the evaporator was above the compensation chamber. At an evaporator temperature of 75^0C, an evaporator heat load up to 75W could be reached with thermal resistance of about 0.2^0C/W [10]. The simple analytical model of self-exciting oscillation based on an oscillating feature observed. The reciprocal excitation of pressure oscillation due to changes in the heat transfer rate caused by the oscillation of the void fraction was investigated. Oscillation of the void fraction was out of phase with the pressure oscillation by $-\pi/2$. This model indicates that an optimal charge ratio exists for a particular PHP. It was found that, if the charge ratio is too high, the PHP will experience a gradual pressure increase followed by a sudden drop [11].The performance on LHP using ammonia, water and acetone as working fluid ware studied and observed that, the operating limits are different for each working fluid. The water and acetone PHPs are limited by the absolute vapor pressure at low power levels within 3000 W. While ammonia exhibits desirable heat transfer characteristics [12]. The investigation of oscillatory flow in a closed-end pulsating heat pipe with 5 turns has been carried and the results showed that for a PHP, the frequency and amplitude of oscillation were independent of the number of turns. The motion and amplitude of the vapor plugs was identical for both even and odd vapor plugs after reaching steady state, but both were out of phase by a the factor of π. As the number of turns increased above 6, the odd and even numbered plugs no longer showed identical oscillation. Each plug lagged slightly behind the next. Each plug remained out of phase by π [13].A prototype LHP has been tested with ammonia and propylene as working fluids. The result shows that at low sink temperature, the PHP performance was similar for heat loads less than 100 W. For higher heat loads, the thermal conductance of the ammonia PHP was approximately four times greater than that of the propylene. It was concluded that, propylene is a good fluid since it has a lower freezing point and relatively good heat transfer properties [14].The thermal and hydrodynamic performance of flat heat pipes were studied for various heating and cooling conditions and it is concluded that, the basic concept of heat pipe is only valid for less thermal conductivity wall materials. And by reducing the size of heat source will reduce the performance because of jump in peak wall temperature [15].

From the literature, it was found that the application of heat pipe is numerous which can be used to heat transfer in smallest IC to aerospace applications and concluded that, the performance of all the types heat pipes depends on method adopted to reject heat, gravitation effect, working conditions, wick material used, diameter of tube used, type of working fluid, filling ratio.

In the present work, it was aimed to use different working fluid with various filling ratio of 50, 60, 70 and 80% to check the heat transfer capability of pulsating heat pipe. This was achieved by selecting copper tube with 2.8 mm inner diameter. The data were taken from DAQ and the response were plotted and analyzed.

3. METHADOLOGY

The mechanism of pulsation of water and bubbles in capillary channel with different diameters varying from 2 to 5mm were studied and tube diameter of 2.8 mm was optimized. From literature it was found gravity affects the surface tension forces and hence the performance of heat pipe varies based on orientation. To conduct the experiment, the tubes are kept in vertical direction. The experiment was carried out keeping the number of turns to an optimal value of 3 and is constant throughout the study. The overall length of the tube selected as 210 mm. evaporator section was made using DC mica-thermic heaters (250 mm long, 50 mm width and 6 mm thick) were attached to the copper block which has the 230 V, 25-75W capacity and insulated completely. The condenser section is done with the dimension of 250x100x40 mm^3. Water is used as a cooling fluid in condenser. Chromel-alumelthermocouples (Omega type K with ±1 ^OC accuracy) of 1.5 mm diameter were used to measure temperature at different location. The line diagram of experimental setup is as shown in figure3.1.

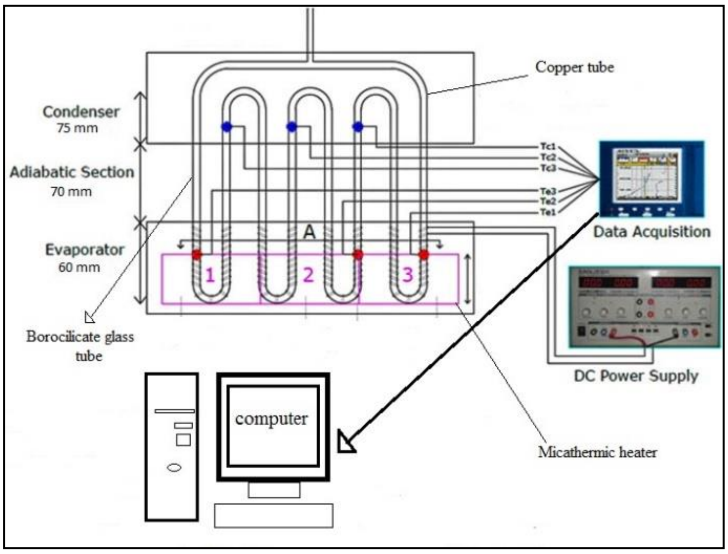


Figure3.1: Experimental setup

4. EXPERIMENTAL PROCEDURE

The test setup consists of evaporator, adiabatic, and condenser section. In the experiment, the heat transfer parameters were measured for two liquids (methanol and acetone). After filling the working fluid, the copper tube was sealed at the top using cork.The condenser section was made as hollow tank in which water is used as cooling medium. The CADD model of assembled heat pipe setup with evaporator, condenser and adiabatic region is shown in figure 4.1.

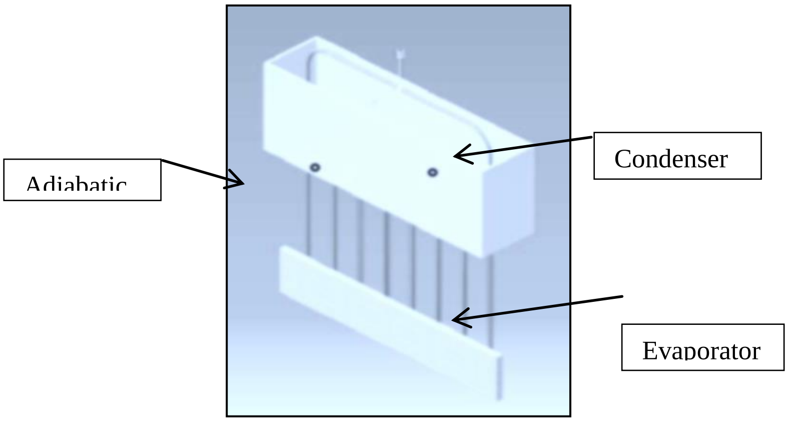


Figure 4.1: CADD model of heat pipe arrangement

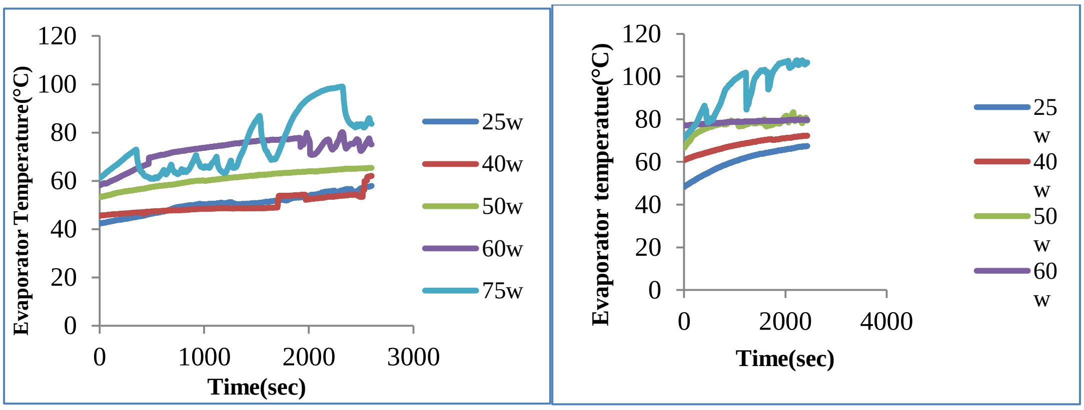
The tests were conducted on the heat pipe, in which heater was switched on and the temperature rise were observed at regular intervals till the steady state. After achieving of steady state, the temperatures at the various points were noted. This experiment was repeated for different heat inputs, different fill ratios, and for different working fluids. Various plots were drawn to study the performance of the heat pipe setup to optimize the fluid inventory. The different heat inputs were achieved by changing the output voltage. The fill ratios used in this experiment were 50%, 60%, 70%, and 80% volume basis for both the working fluids. All the temperature readings, at the various points on the heat pipe surface were taken for both working fluids and for all the fill ratios after reaching steady-state condition. Ethanol and acetone were used as working fluid because of their good thermo physical properties like low dynamic viscosity, high specific heat, and low surface tension effect.

5. RESULTS AND DISCUSSIONS

Experiments were conducted to evaluate the performance of PHP using two parameters, as startup power and thermal resistance. The startup condition is very important for the stable oscillating motion occurring in a PHP and it depends on many factors like the filling ratio, tube geometry, wall temperature variation, heat flux level, physical properties of working fluid, heating and cooling modes, transient heat transfer process, initial temperature, and so on.

5.1 Effect of Heat input on Evaporator temperature for various working fluids and filling ratio

Heating part of the setup is an evaporator; since heat transfer is mainly due to pulsating bubbles shuttling between evaporator and condenser. At a stage where the systems performance is high the heat flux is transferred to condenser by these pulsating bubbles. As pulsation takes place the heat from evaporator is absorbed by fluid and as latent heat required to vaporize. This causes in sudden rise and fall of evaporators temperature and is profound over a period of time. The behavior of evaporator temperature for ethanol and Acetone with various filling ratio of 50 %, 60% and 70% over time is plotted in figure 5.1(a),5.1(b) and 5.1(c) respectively.

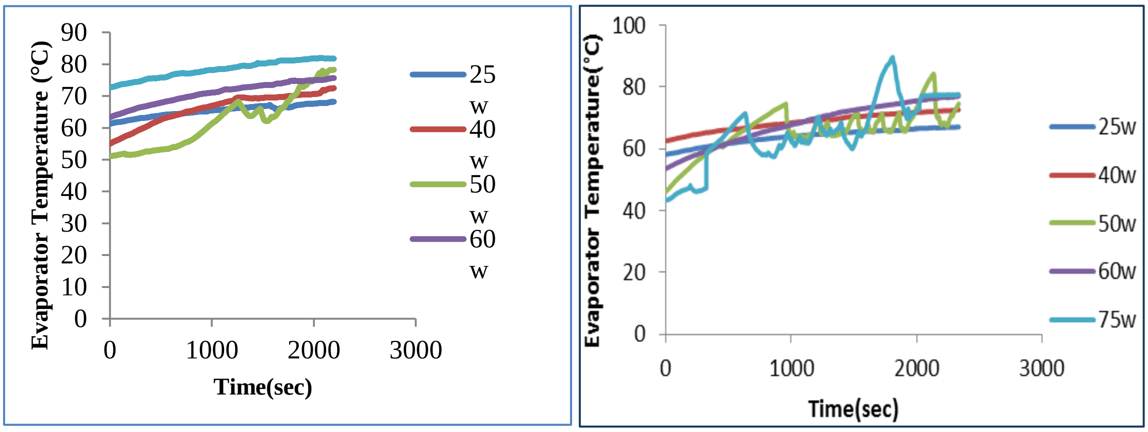


a) Working fluid-Ethanol. **b) Working Fluid-Acetone**

Figure5.1(a): Evaporator temperature v/s Time (Filling ratio=50%)

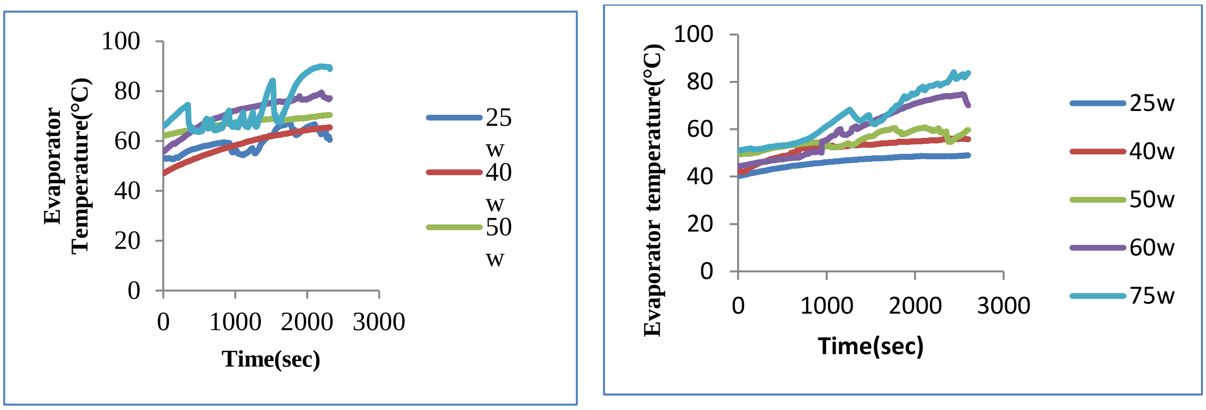
As the evaporator temperature increases, at some instant of time the power produced increases to commence the pulsating action for both the fluids. It is observed that, at 75W there is a sudden drop in the temperature for ethanol and then this temperature remains constant for certain period and it again starts increasing, this is the point where the pulsating action begins,but in case of Acetone, it is observed increasing trend from the beginning for 75W. Also, there is a small variation that can be found after 2000 seconds for a heat input of 50W. Though these variations are uniform and small they do not have reasonable band width. Also it is clear that the evaporator temperature increases as the time increases this caused the decreasing in surface tension and latent heat of both working fluids. Gradually the flow regime changes from slug flow to churn or annular flow, resulting in a liquid film in the evaporator which gets thinner and thinner, at last dry spots and ultimately a stable dry out occurs.

For 60% filling ratio, for Ethanol the evaporator temperature increases linearly for all heat inputs but for 50W of heat input it is found sudden raise in temperature, but. Coming to Acetone, for 75W curve shows a sharp increase in temperature in the beginning, but after 1000 seconds a steady behavior of uniform fluctuations of evaporator temperature with desired band width can be observed. This behavior does not last long as the fluctuations similar to previous case become dominant. This indicates a dry our situation of working fluid in the evaporator section.



a) Working fluid-Ethanol b) Working Fluid-Acetone

Figure 5.1(b): Evaporator temperature v/s Time (Filling ratio=60%)



a) Working fluid-Ethanol. b) Working Fluid-Acetone

Figure 5.1(c): Evaporator temperature v/s Time (Filling ratio=70%)

At 50W heat input though the temperature of evaporator rises sharply initially, there is a steady state period which dominates for major part of time. Uniform fluctuations of evaporator temperature with desired band width prove that 50W is the optimal heat input for acetone for pulsations to start and sustain.

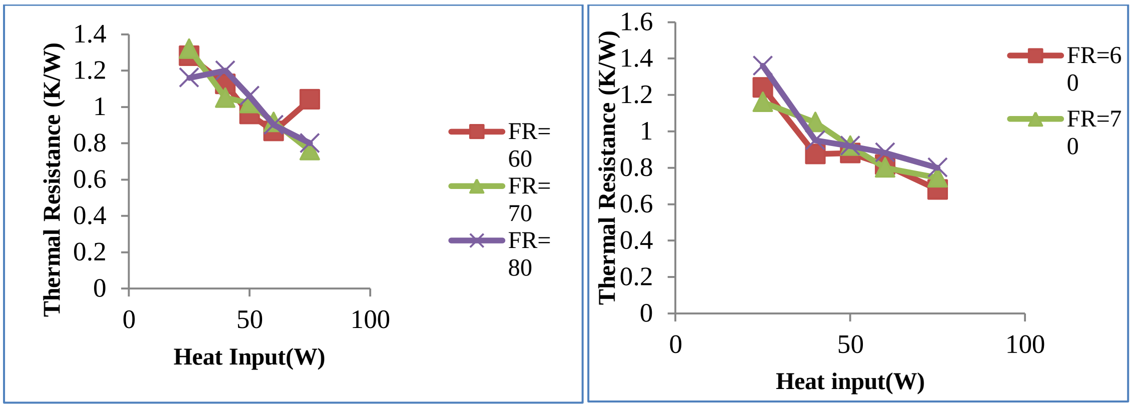
For 70% filling ratio, for Ethanol, 75W line in the graph shows that there is a sudden drop in the temperature and then this temperature remains constant for certain period and it again starts increasing, this is the point where the pulsating action begins. Other curves corresponding to heat input 60W, 50W, 40W are linearly increasing. For Acetone, Curves corresponding to 25W and 40W do not show any impressive improvements at 70% filling ratio and the increase in evaporator temperature is approximately linear at 60W and 75W. This is due to no proper heat conduction because of constrained degree of freedom for Taylor bubbles due to high volumetric filling ratio.

5.2 Effect of Heat Input on Thermal Resistance for Ethanol and Acetone

The thermal resistance of the PHP is generally given by

$$R = \frac{Te - Tc}{Q} \text{----------} (1)$$

Where, Teand Tcbeing the average wall temperatures of the evaporator and condenser respectively and Q is the input power. Figure5.2shows the variation of thermal resistance with different heat input. As the heat input increases the thermal resistance decreases and hence the operation becomes much easier at higher heat input values. It is observed from figure 5.2(a),that for 80% fill ratio of ethanol the thermal resistance is higher at the beginning until 40W of heat input, and resistance is reducing for higher heat input. We can observe from figure 5.2(b) that, for fill ratio 80% for acetone the air bubbles present is less and it offers more thermal resistance in the beginning, but it has the advantage of lasting longer because the dry out condition is delayed but it takes place a little earlier in 60% fill ratio.



a) Working fluid-Ethanol. **b) Working Fluid-Acetone**

Figure5.2: Thermal Resistance v/s heat input (Fluid= Ethanol)

6. CONCLUSIONS

The experimental investigation on a three-turn pulsating heat pipe has been carried out. The effect of working fluid, filling ratio on the performance of PHP in terms of thermal resistance, heat input were studied and following conclusions were drawn from the experiment:

More random and intermittent motion of the working fluid with higher perturbations are observed at lower heat input upto 40W compared to higher heat inputs of 50 W andabove. From the various graphs and data obtained it can be seen that Acetone shows better performance over Ethanol. Among the working fluids used, optimum results are obtained with acetone at 60% fill ratio with a minimum heat load of 50 watts, and with ethanol at 50% filling ratio with a minimum heat load of 75W. There is continuous circulation of liquid inside the PHP in the form of vapor bubbles and liquid slugs. It is observed that as the heat input is increased the thermal resistance decreases and heat transfer coefficient increases which is a good indication of the PHP for different applications. Lower thermal resistance and higher heat transfer coefficients can be seen with the use of 50% to 70% filling ratio.

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