Experimental Studies on the Thermal Performance of a Closed Loop Pulsating Heat Pipe Using Water-ethanol Binary Working Fluids

P.Venkataramana, P. Vijaya Kuamr, B. Bala krishna

Abstract*: The closed-loop pulsated heat pipe is a self-excited operated thermally with a two-phase heat transfer system, which controls the functioning of heat from one place to another place with no temperature drop. The Experiment is conducted on a single closed-loop pulsated heat-pipe is made of brass with various filled ratios 40%, 50%, 60%, 70% and 80%. Experimental investigations are conducted for the heat inputs ranging from 20 watts - 100 watts. The utility of other than conventional fluids were not used by any researcher and hence try to estimate the performance of PHP using azeotrope mixtures as working fluids. When used as a mixture they exhibit less boiling point rather than individual components. In this regard azeotrope mixtures of ethanol-water having weight proportions' of 90.5% and 4.5%, respectively, and acetone/water, acetone/ethanol having volume ratios 1 : 1 is utilized as working fluids under the experimental way. Performance of a PHP has been derived in terms of estimation of thermal resistance or coefficient of heat transfer. Out of various mixtures verified based on that attains less thermal resistance or maximum heat transfer coefficient would be considered as a most suitable working fluid for PHP operation.

***Index Terms*: Single loop pulsating heat pipe, heat transfer coefficient, thermal resistance, temperature**

I. INTRODUCTION

Technology development in the electronics field leads to a maximization in density interfacing and define the nature of miniaturized modern electronic devices. This results the consumption of more heat flux ranges at chip level [1]. So as to fulfill the requirement of junction temperature in the way of performance enhancements in cooling schemes are needed. At this point, thermal management issues are predominantly increasing significantly for semiconductor manufacturers and electronic apparatus. The main task of regulating acceptable junction temperatures by vanquish the heat losses from interfacing circuit chips, it is eminent challenge to researchers and engineers.

Cooling of semi-electronic devices will be typically in order to explain in the following ways: (i) Moderate temperatures sustained in chips over the high degree of compactness of heat substance, (ii) debauched the heat flux of the system, (iii) computer center‘s thermal management, system, adjacent tele-communication systems, offices, etc, [2]. Different elements like joints temperatures, size of chips, dissipation of ambient and power temperatures has incredible effect on design of system. Simplify the thermal performance in [3],[4] with more number of PHPS initiated to be minimized with respect to change in inclination angles. PHPS are having smaller in diameter to accomplish the good at low inclined angles over several years, R&D departments of several industries which is highly focused on reduced size of electronic apparatus. To check the inability values and performance consistently well to distribute the desired results in capillary tubes yields to progress of single closed-loop with pulsating heat-pipes with no check values [5]. Generally, thermal management is categorized as active and passive cooling methods. Mechanical assisted cooling systems are treated as active cooling methodology. The merits of active cooling methodology are, consisting of greater cooling capacity. They provide such an efficient cooling, that the systems can be cooled to even lower than ambient temperatures. The air-cooled jet, spray cooling, forced convention, thermo-electric refrigeration and cooling, etc, [6].

The flow pattern in a PHP is analyzed via visualized conducted studies [7]. The studies on flow-visualization are carried on single closed-loop with pulsated heat-pipe developed of copper bus. The slug-flow with low-magnitude oscillations was observed at lower heat input. Sustainability of annular flow had become very difficult when fill-ratio is maximized within 70%. In experiment studies on a closed-loop single turn PHP [9],[10]. The transient state & steady state response is carried on several operating conditions. The outcome results of experiments represented an intermittent on working of fluids at low heat input.

The traditional passive cooling methods are heat sinks and heat spreaders to electronic packages. These systems requires limited space the advanced passive cooling techniques are more suitable over active-cooling methods. But they are limited to what they can achieve. At present technology development shows the usage of storage as thermal energy with particle changes and interfacing to heat pipes on electronic packages. These methods are utilized to attain high cooling capability and it is ideal for electronic cabinet cooling.

A. Construction of Conventional Heat pipe and its Working

Any ordinary heat pipe likewise comprises the segments, for example, a fixed pipe loaded up with weak formation alongside a low amount of operating liquid which is in stage harmony with vapor.

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Entire length of heat pipe is isolated into 3 sections: evaporation segment, condenser segment area and adiabatic segment (Figure.1). In view of particular plan & various appliances, approved heat-pipe is furnished on heat-sinks with-out or with adiabatic segments. The connected heat source outside to the evaporator segment directs via pipe divider & transmits the operating liquid by means of the wick modules are vaporized. High weight vapor is transformed via adiabatic segment to for condensing and attains consolidated discharging inert heat vaporization on cooling medium. The condensate streams back to the evaporator area because of the slim siphoning activity made by the wick structure. Accordingly, the nonstop transport of inactive heat of vaporization is occurred from evaporator to condenser area of the heat pipe. For whatever length of time that adequate narrow weight is kept up to siphon the condensate back to the evaporator this procedure will proceed.

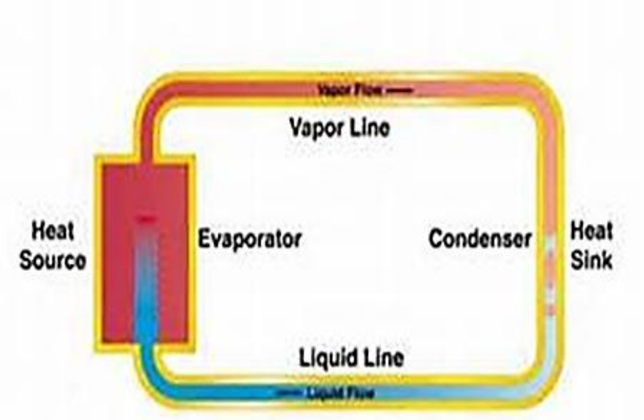

Fig.1, Schematic diagram of a conventional heat pipe

The variation in the curved upper surface of a liquid in a tube and the surface tension of the working fluid will have the strong development on the capillary pressure existed along the fluid-vapor interface. The adjustment in capillary pressure is seen along the pipe because of constant variety in bend of the menisci along the fluid vapor interface .subsequently the capillary pressure gradient has become a liable component to circulate the liquid against unfavorable pressure losses and body forces.

The adjustment in vapor pressure is accounted for a heat pipe due to inertia, viscosity, evaporation and buildup impacts, while that of the fluid changes fundamentally because of viscous effects. At low vapor stream rates, the nearness of zero local pressure slope causes the formation of flat fluid-vapor interface close to the condenser end top. Within the presence of body forces such as gravity, the fluid pressure drops to a great extent and hence required bigger capillary pressure to drive the fluid to the evaporator area. At moderate vapor stream rates, dynamic effect causes the vapor pressure drop and recuperation along the condenser area. The ordinary heat pipes are given the measurements in the scope of couple of centimeters of length and millimeters of diameter up to lengths in excess of 10 meters and diameters of the request of numerous centimeters.

B. Limitations of Conventional Heat Pipes

The traditional heat-pipes are incredible heat exchanging apparatus but the importance is confined mainly to transforming the low measured heat over the very short separators when the condenser and evaporator are at equal horizontal levels. With respect to the restriction of regular part on traditional heat pipes which are mainly functioning based on high range pressure losses significant of fluids flow via permeable limits. Likewise, there will be viscous collaboration between the vapor and fluid stages, called entrainment losses. Including exchange of substantial measure of heat over the very long distances, the performance of heat pipes is gravely influenced based on maximization of losses. Over the traditional heat pipes which are more sensitive for adjusting the gravitational fields. In top heat mode positions (evaporator at the top, condenser down), the loss pressures because of mass forcing on gravity fields which increases the overall pressure loss and accordingly affect the over-all efficiency of heat transfer rate.

The outcome results on several constraints on distinctive arrangements including auxiliary adjustments to typical heat pipe are explored. A portion of the advanced structures of heat-pipe with additional arterial tube relatively reduced hydraulic-resistance for return fluid to heat furnishing zone while others supports particular partition of the fluid phases and vapor of an operating liquids at the area of transportation. Thus, these heat-pipes are suitable to maximize the heat transportation length and significant transfer amount of heat they are exceptionally dedicated for introducing the field of gravity. The several merits furnishing by spatial division of transportation usage & line of artery non-capillary tubes are integrated together in closed-loop heat pipes commonly named as PHPs. Based on result, this closed-loop schemes provides the more possible developments on heat-pipes with greater heat transfer capability while sustaining ordinary activity at any introduction in the gravity field.

II. EXPERIMENTATION

A. Experimental Setup of Single loop PHP

To understand the heat transfer and liquid-flow rate characretics of closed-loop PHPs are studied based on behaviour under non-expulsion conditions, this experimental setup was built. The setup was built with air cooling arrangement in the condenser. The preliminary results highlighting the effect of heat input, working fluid and orientation are obtained from this setup. This experiment also proved valuable as the flow visualization studies are carried out from the same. The basic elements in this experimental setup are glass tubes, brass tubes, silicon-rubber tubes, non-retuned values, thermo-couples and wound coil heaters. Generally, the tube-material is designed by brass because it acts as conductor of heat transform. The diameter of internal tube is 2mm and external is 3 mm. The tube is developed into a U-shaped bow with a sweep range of 35mm. The glass-tube is integrated in between U-shaped brass tube and it acts as adiabatic structure and furnishes the flow-visualization. The length of utilized glass tube is 50mm, and is designed by using borosilicate which is operated at 1200ºC temperatures. The silicon rubber tubes with internal structure diameter is 2mm and are regularly used as connecting points between brass and glass tubes. They have opposed temperatures up to 400ºC. So as to sustain the uni-directional liquid flow based on non-returned valves and is made up of stainless steel. The eight K-type thermo-couples are used to estimate the temperatures. The thermo-couples can also measure temperature ranges upto 1000ºC.

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The diameter of thermo-couple wire is 1mm and the 4 are associated in condenser and evaporator structures at equivalent separations. A twelve-channel computerized temperature pointers are utilized to observe the temperatures ranges at several areas. A wound–coil heater is appended to evaporator the several sections which acts as the sources of heat input. The heating coil is developed by Cathleen (20% Cr and 80% Ni). A twisted Teflon based tape is pasted at coil to regulate the heat losses in between the heat-pipe and coil e. In experimental setup Azeotrope mixture is utilized as a working fluid like water –ethanol and water-acetone etc., are used. The working liquid is highly infusing into the heat pipe by utilizing syringe.

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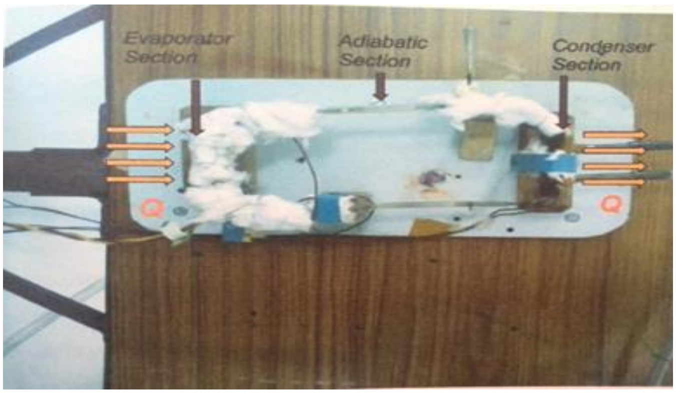

Fig.2, Pictorial view of a single loop PHP with water cooling

B. Experimental Procedure

1. Before leading the analysis, it is ensured that there is no liquid inside the tubes.
2. The required measure of liquid is then filled through a syringe by opening one end of the valve that the liquid directly enters the evaporator segment.
3. Simultaneously, air is filled through the projection provided on the brass tube utilizing another syringe. This is done to ensure formation of liquid slugs and vapor bubbles in the PHP.
4. The required heat input is set in the power supply unit.
5. Water is utilized for cooling the liquid in the condenser section.
6. The device is worked in the horizontal mode and with azeotrope working fluids viz., water-ethanol and water-acetone.
7. Transient tests are conducted and the different temperatures are recorded from the digital temperature indicator. The experiments are continued relentless state is reached.

III. RESULTS & DISCUSSION

The experiments on transient conditions are validated with several working fluids such as ethanol, acetone, methanol and water with temperature variations with time is observed. The experiment is led in a vertical and horizontal mode which is continued come upto relentless states. In this mode, vertical set-up was functioning with bottom heating mode, i.e, condenser up and evaporator down positions.

A. Variation of temperature under the Influence of water/acetone mixture

Fig.3 and 4, shows Evaporator temperature and condenser temperature of water/acetone PHP with the filling ratio of 50% and different heat inputs. The volume ratio of acetone and water is 1:1. For Heat input less than 60W, evaporator temperature of water/acetone is lies in between evaporator temperature of water and evaporator temperature of acetone. For power input larger than 60W, evaporator temperature of water/acetone is more than evaporator temperature of acetone and evaporator temperature of water. Moreover, evaporator temperature of water/acetone has the same trend of evaporator temperature of acetone and evaporator temperature of water/acetone is more than evaporator temperature of acetone at heat input range from 20W to 100W.

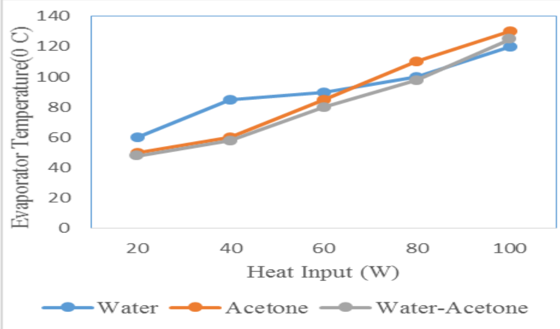

Fig.3. Variation of evaporator temperature with heat input operating with different working fluids

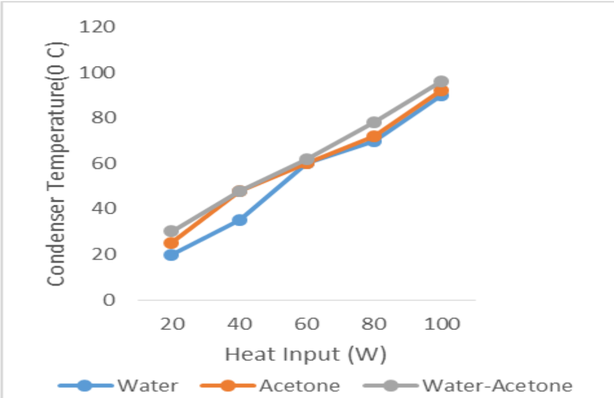

Fig.4. Variation of condenser temperature with heat input operating with different working fluids.

B. Variation of thermal resistance under the Influence of water/acetone mixture

Finally the effectiveness of the pulsating heat pipe is indirectly brought in terms of thermal resistance and convective heat transfer co-efficient. The thermal resistance values are determined at various heat inputs utilizing condition. Fig.5 shows thermal resistance values decreased with increase in heat input for acetone, water and Water/acetone mixture. Acetone exhibits lower values of thermal resistance at all heat inputs compared to the other working fluids. This is because of temperature distinction between the evaporator and condenser is bring down in case of acetone.

The thermal resistances have the results of acetone less than water/acetone less than water.

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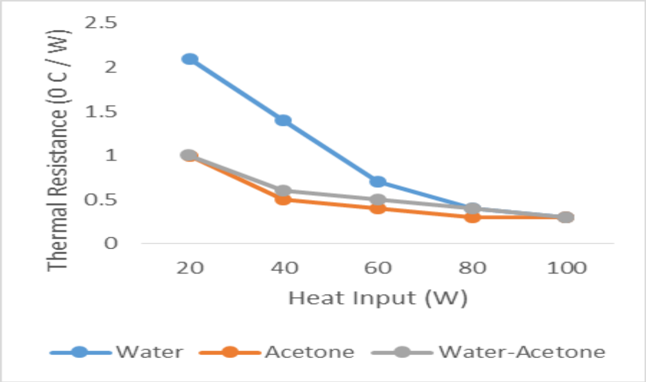

Fig. 5. Thermal resistance variation with heat input operating with different working fluids

C. Variation of temperature under the Influence of water/methanol mixture

Fig.6 and 7, shows Evaporator temperature and condenser temperature of water/methanol PHP with the filling ratio of 60% and different heat inputs. . The volume ratio of acetone and water is 1:1. The evaporation zone temperatures have the characteristics of evaporator temperature, water/methanol less than evaporator temperature, methanol less than evaporator temperature, water. For power input lower than 60W, condenser temperature of water/methanol is closer to the condenser temperature of methanol. For heat input more than 60W, condenser Temperature of water/methanol is lower than condenser Temperature of methanol and condenser Temperature of water.

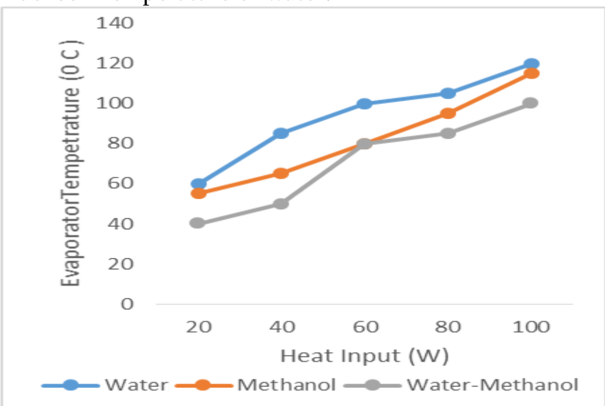

Fig.6. Variation of evaporator temperature with heat input operating with different working fluids.

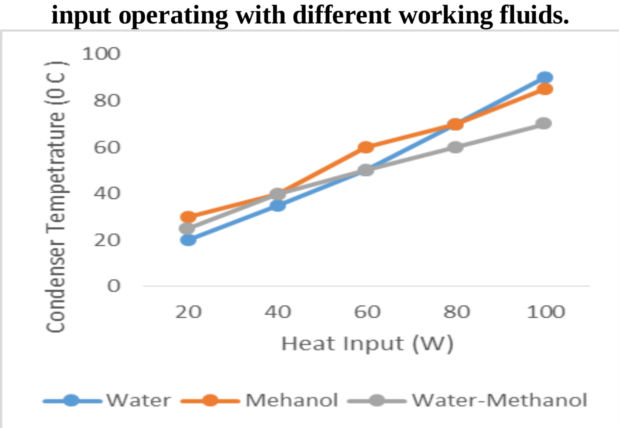

Fig.7, Variation of condenser temperature with heat input operating with different working fluids.

D. Thermal resistance variation under the Influence of water/methanol mixture

The thermal resistance values are determined at different heat inputs using. Fig.8 shows the thermal resistance values decreased with increase in heat input for water, methanol and Water/methanol azeotrope mixture. The thermal resistances have the results of water/methanol is less than methanol.

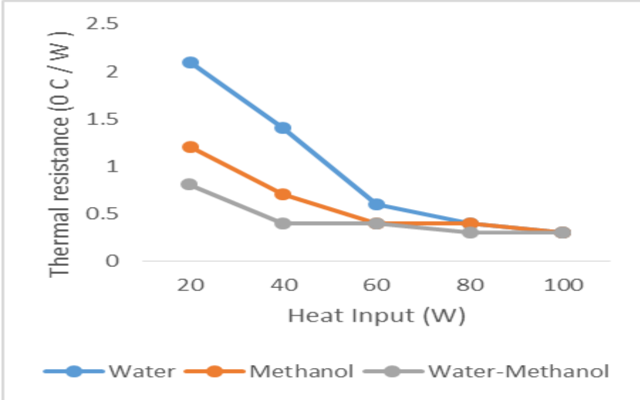

Fig.8. Variation of thermal resistance with heat input operating with different working fluids.

E. Variation of temperature under the Influence of water/ethanol mixture

Fig.9 and 10 demonstrates the effect of azeotrope mixture (water-ethanol binary working fluids) on the evaporator and condenser temperature respectively. From fig.8, it shows that clear evaporator temperature for pure ethanol and azeotrope mixture of ethanol (95.5% wt.) and water (4.5% wt.) is lower when contrasted with water. Likewise demonstrates that the evaporator temperature for ethanol and azeotrope mixture of water and ethanol is about same at all heat inputs. Fig.10 presents that the condenser temperature is almost same for the three fluids i.e. water, ethanol and water/ethanol between the heat input ranges from 8 watt to 24 watt. After 24 W, condenser temperature for water is lower than the ethanol and azeotrope mixture. The evaporator and condenser temperature contrast is about equivalent for azeotrope mixture and pure ethanol but for pure water the temperature difference is very high and hence more thermal resistance is appeared.

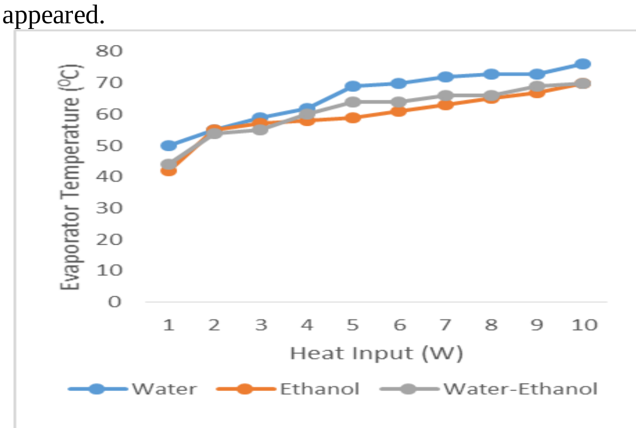

Fig.9, Variation of evaporator temperature with heat input operating with different working fluids.

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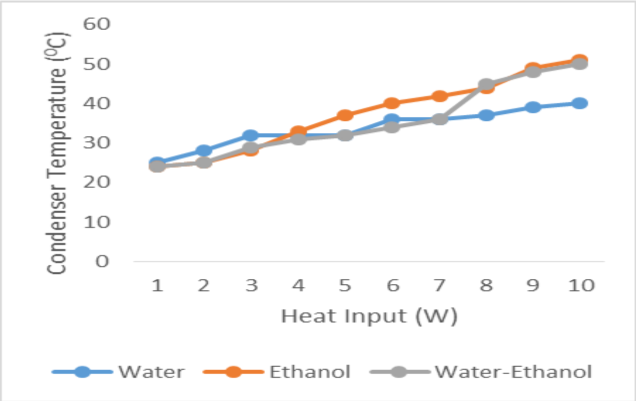

Fig.10, Variation of condenser temperature with heat input operating with different working fluids.

F. Variation of thermal resistance under the Influence of water/ethanol mixture

Fig. 11 concludes that the thermal resistance for ethanol and azeotrope is same between heat input ranges from 8 watt to 24 watt thermal obstruction of water is more than the azeotrope and ethanol for all heat inputs. It is discovered that there is no measurable contrast has been recorded for the PHP running with azeotrope mixture and the PHP running with pure ethanol. Hence, the ethanol PHP and azeotrope PHP is more successful than water PHP.

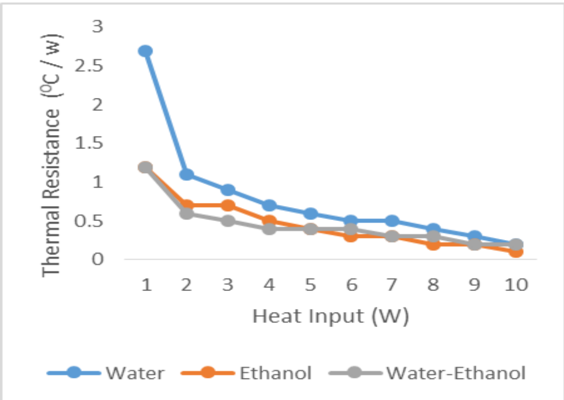

Fig.11. Variation of thermal resistance with heat input operating with different working fluids.

G. Flow Visualization Studies

The complex thermo hydrodynamics of PHP can be well understood by studying the flow patterns in a PHP. The visualization experiments conducted during the course of the present research showed that various flow patterns exist in PHP under different working conditions. The different flow patterns observed during the experiments was bubble – liquid slug flow, semi annular flow and annular flow. The pure slug flow is observed at a low heat load of Q = 8W (Fig.12). When the flow is pure slug flow, the bulk movement of the fluid tends to stop for a while and then restarts in a cyclic manner. The slug / bubbles were found to vibrate with high frequency and low amplitude about a mean position. Three kinds of bubbles were observed during the flow viz. small bubbles, vapor plugs and long vapor plugs. As the liquid slug passes through the evaporator section, a small amount of liquid was left behind resulting in continuous boiling. This produces bubbles smaller than tube diameter. The vapor plugs whose sizes are almost equal to the tube diameter are predominantly produced due to the liquid thin film between the bubble and the tube. Long vapor bubbles were also observed during the flow. These bubbles were seen collapsing during the flow.

When heat input was increased, the transition from slug flow to semi annular/ annular flow was observed. The slug flow, annular flow co exists in semi annular flow and proves to be beneficial in terms of increasing the heat transfer in a PHP.

Fig.12. Flow observed in PHP at different Heat Input.

IV. CONCLUSION

The following conclusions are drawn from the experimental work on a single loop pulsating heat pipe.

1. In this experimental work, water/acetone azeotrope mixture proved to be a better working fluid compared to the azeotrope mixture of Water/methanol and water/ethanol. The thermal resistance decreases with the increase of the heating input. The thermal resistance decreases more slowly and the differences of the thermal resistances with every working fluids are smaller at Heat input $Q \geq 60W$. However, the pattern is opposite at $Q \leq 60W$.
2. PHP with water/acetone Heat input less than 60W, Evaporator Temperature of water/acetone is lies in between Evaporator temperature of acetone and evaporator temperature of water. For power input larger than 60W, evaporator temperature of water/acetone is higher than evaporator temperature of acetone and water. Moreover, evaporator temperatures of water/acetone have the same trend of evaporator temperature of acetone from 20W to 100W.
3. PHP with water/methanol the thermal resistances have the results of Rwater/methanol < Rmethanol < Rwater. The evaporation zone temperatures have the characteristic of Te, water/methanol < Te, methanol < Te, water. Water/methanol PHP has better heat transfer performance than pure working fluids PHP and acetone/water PHP.
4. It is seen that at a fill proportion of 60%, the PHP is found to display better heat exchange qualities.

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