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Performance Analysis of Pulsating Heat Pipes Using Various Fluids

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Abstract

Pulsating heat pipes are recently developed heat exchanging devices in which there is no need of external source for the movement of working fluid in the heat pipe. This gives many advantages like, good thermal performance than that of conventional heat exchangers. Pulsating heat pipes have more advantages. Some of them are, thermal conductivity of the heat pipe is several times is greater and its relative weight is very less, compared to that of best solid conductor. Pulsating heat pipes are widely used in electronic devises and also in space applications because of achieving forced circulation without any external source in the vacuum. In the present experiment, the performance characteristics of pulsating heat pipe like, thermal resistance, temperature variation with time at different points of the pulsating heat pipe are being investigated experimentally. Ethanol and Distilled Water are being used as working fluids with the filling ratio of 50%.A copper tube of inner diameter 2mm is being used as pulsating heat pipe heat pipe material.

1. INTRODUCTION:

A heat exchanger is a device that is used to transfer thermal energy between two or more fluids, between a solid surface and a fluid, or between solid particulates and a fluid, at different temperatures and in thermal contact. In heat exchangers, there are usually no external heat and work interactions. Typical applications involve heating or cooling of a fluid stream of concern and evaporation or condensation of single or multi component fluid streams. But pulsating heat pipes are the heat exchanging devices where there is no pumping of fluid from heater to the condenser. The heated fluid automatically pulsates from the evaporator to the condenser.There has been shift in cooling mechanism in the past few years and pulsating heat pipes have emerged with many advantages and the difference between the three heat mechanisms is shown below.

1.2 Heat pipe:

A Heat pipe is a heat-transfer device that combines the principles of both thermal conductivity and phase transition to efficiently manage the transfer of heat between two solid interface. The heat pipe has two regions evaporator and condenser. There is an adiabatic region which separates condenser and evaporator. The heat pipe has wall, the wick structure and the space for the working fluid.

1.3 Working principle of heat pipe:

The Heat is absorbed in the Evaporator region and is carried out through the pipe by the evaporation of the fluid by absorbing the heat. The high temperature vapor moves toward the condenser by the action of buoyancy force. At the condenser it rejects the heat by convection and converts into liquid droplets. These droplets move to the evaporator due to gravity through the wick material. Thus we can observe that there is a voluntary movement of the fluid from the evaporator section to the condenser section and from condenser to evaporator.

1.4 Pulsating heat pipe:

A PHP is a complex heat transfer device with a strong thermo-hydraulic coupling governing its performance. It is essentially a non-equilibrium heat transfer device. Pulsating (Oscillating) heat pipe has many numbers of U-turns of tube with capillary diameter .These tubes are evacuated and partially filled with the working fluid. When the diameter of the tube is so small, preferably <2mm then the working fluid distributed itself in the form of vapor slug and liquid slug. When it is compared with the convectional heat pipe, it has no wick material inside the tube.

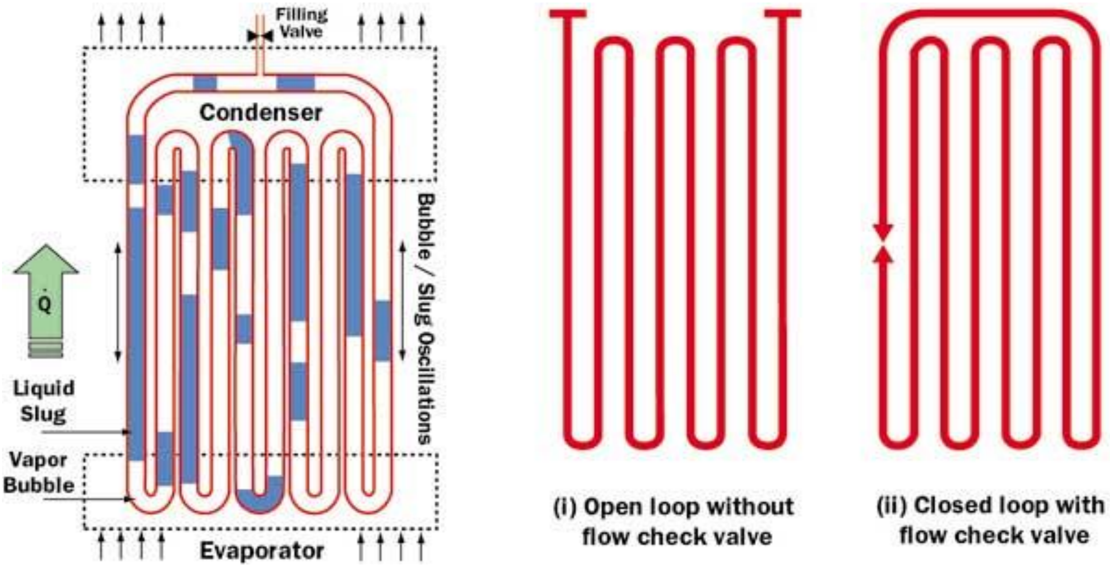

Fig1.4 Schematic diagram of Pulsating Heat Pipe

1.5 Working principle of CLPHP's:

One end of the PHP tube bundle receives heat, transferring it to the other by a pulsating action of the working fluid, generating, in general, a capillary slug flow. While in operation, there exists a temperature gradient between the heated and cooled end. Small temperature differences also exist amongst the individual 'U' bends of the evaporator and condenser due to local non-uniform heat transfer rates which are always present in real systems. Since each tube section between the evaporator and the condenser has a different volumetric distribution of the working fluid, the pressure drop associated with each sub-section is different. This causes pressure imbalances leading to thermally driven two-phase flow instabilities eventually responsible for the thermo-fluidic transport. Bubble generation processes in the heater tubes sections and condensation processes at the other end create a sustained 'non-equilibrium' state as the internal pressure tries to equalize within the closed system. Thus, a self-sustained thermally driven oscillating flow is obtained. There occurs no 'classical steady state' in PHP operation as far as the internal hydrodynamics is concerned. Instead, pressure waves and fluid pulsations are generated in each of the individual tube sections, which interact with each other generating secondary/ ternary reflections with perturbations. It will be appreciated that PHPs are complex heat transfer systems with a very strong thermo-hydrodynamic coupling governing the thermal performance. The cooling philosophy draws inspiration from conventional heat pipes on one hand and single phase forced flow liquid cooling on the other. Thus, the net heat transfer is a combination of the sensible heat of the liquid plugs and the latent heat of the vapor bubbles. The construction of PHPs is such that on a macro level, heat transfer can be compared to an extended surface 'fin' system. Simultaneously, the internal fluid flow may be compared to flow boiling in narrow channels.

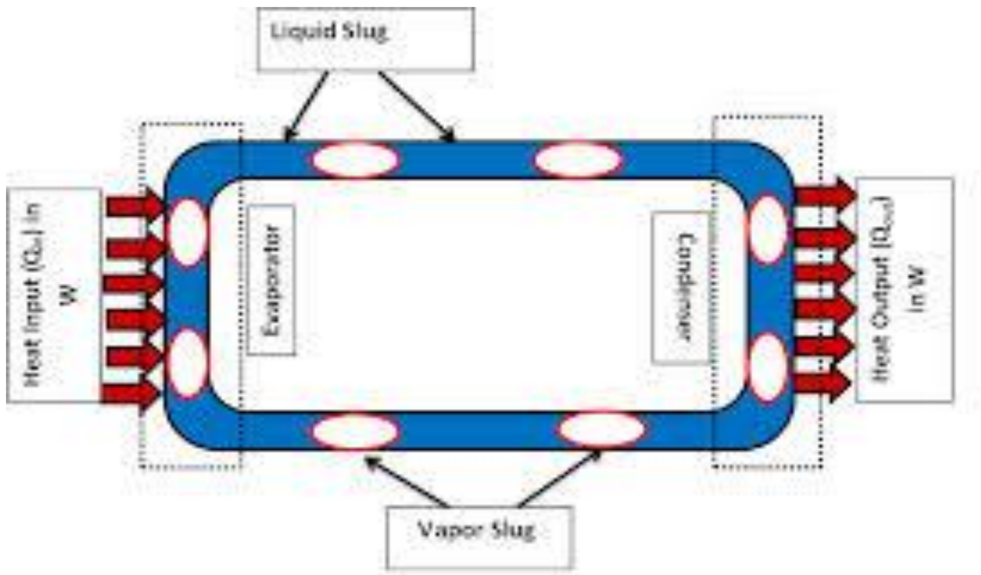

Fig.1.5 Schematic Diagram of Closed Loop Pulsating Heat Pipe

PHPs may never be as good as an equivalent heat pipe or thermosyphon system which is based on pure latent heat transfer. If the behavior is well understood, the performance may be optimized towards classical heat pipes thermosyphons, as a limiting case. At the least, the manufacturing complexities of heat pipes will be avoided. As compared to an equivalent metallic finned array, at the least there will be a weight advantage. Finally, there is always a reliability advantage because of the absence of an external mechanical pump. The available experimental results and trends indicate that any attempt to analyze PHPs must address two strongly interdependent vital aspects simultaneously, viz. system 'thermo' and 'hydro' shows the genealogy of two phase passive devices. Although the representation is not exhaustive, all the systems with relevance to the present interest are depicted. Although all the systems have 'similar' working principles, there are decisive differences that significantly alter the course of mathematical analyses. The family can be subdivided into three major sub-groups, as shown.

2. LITERATURE REVIEW:

Sameer Khandeker and Manfred Groll, published an international paper on the pulsating heat pipes, in which they stated Pulsating heat pipes (PHPs) have emerged as interesting alternatives to conventional heat transfer technologies. These simple looking devices have intriguing thermo-hydrodynamic operational characteristics. In fact, it is rare to find a combination of such events and mechanisms like bubble nucleation and collapse, bubble agglomeration and pumping action, flow regime changes, pressure/temperature erturbations, dynamic instabilities, metastable non-equilibrium conditions, flooding or bridging etc. The discussion was carried out on the mode of pulsating action and the various parameters involved in the PHPs, such as, cooling philosophy of pulsating heat pipes, diameter, heat input and the filling ratio as the defining parameter.

Schmalhofer and Amir Faghri (1991) experimentally analyzed the transient and steady state performance of a copper water heat pipe, and the capillary limit for both modes of heating, such as Block – heated and Circumferential – heated under a step heat input of 50 Watts and 150 Watts in the evaporator section. They concluded that the transient and steady state performance of the heat pipe is the same for both modes of heating. The capillary limit for the block heated mode is higher than that of the circumferential heating mode, because of the shorter adiabatic length. Faghri and Buchko (1991) experimentally and numerically analyzed the capillary limit of a copper water heat pipe with various positions of heat flux in the evaporator section.

Gi Hwan Kwon, Sung Jin Kim (2015) [1] have done an experimental investigation on the thermal performance of a micro pulsating heat pipe with a dual-diameter channel. A Design guideline for the MPHP's with a dual-diameter channel to have orientation-independent thermal performance was suggested. Rectangular channels with dual hydraulic diameters were engraved on a silicon wafer to form a meandering closed-loop MPHP with 5 turns. Using thermometry and high-speed photography, a series of experiments was performed to address the effect of a dual-diameter channel on operational characteristics of the MPHP filled with Ethanol and FC-72 at various input powers and inclination angles.

Shinzo Shibayama and Shinichi Morooka (1979) experimentally and theoretically studied the capillary limit, such as the maximum heat transfer limit in a heat pipe with respect to wick characteristics, friction losses and capillary properties. Pruzan et al (1990) analytically predicted the steady state heat flux limits in a sintered wick heat pipe, with various geometrical parameters in the wick structure such as the wick thickness, effective capillary radius of curvature, porosity and heated wire diameter.

3. RESULTS AND OBSERVATIONS:

The results for the parameters that are measured in this experimental investigation of pulsating heat pipe are discussed below:

3.1 Performance parameters to be measured:

- Thermal resistance (Rth)
- Temperature variation with time for the given heat input

3.1.1. Thermal resistance (Rth)

Thermal resistance is measured as the ability of the fluid to obstruct the flow of heat from one point to the other. The thermal resistance can be considered as a performance parameter of a working fluid. Lesser the thermal resistance more will be the heat transfer coefficient.
In this experiment the performance of pulsating heat pipe using ethanol and distilled water is experimented. The closed loop pulsating heat pipe of inner diameter 2mm is filled with one of the fluid with a filling ratio of 50% and the variation of temperature is observed for every 2 minutes interval of time at 100 watts, 120 watts 1nd 140 watts.

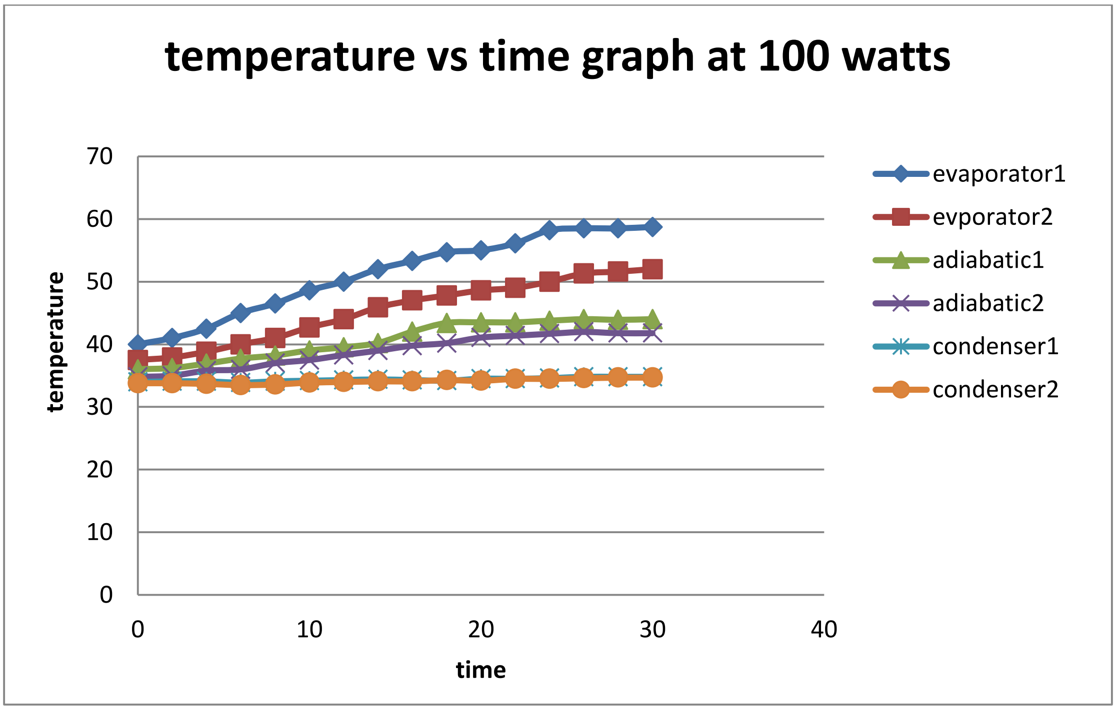

Fig 3.1 temperature variation with time at 100 watts(ethanol)

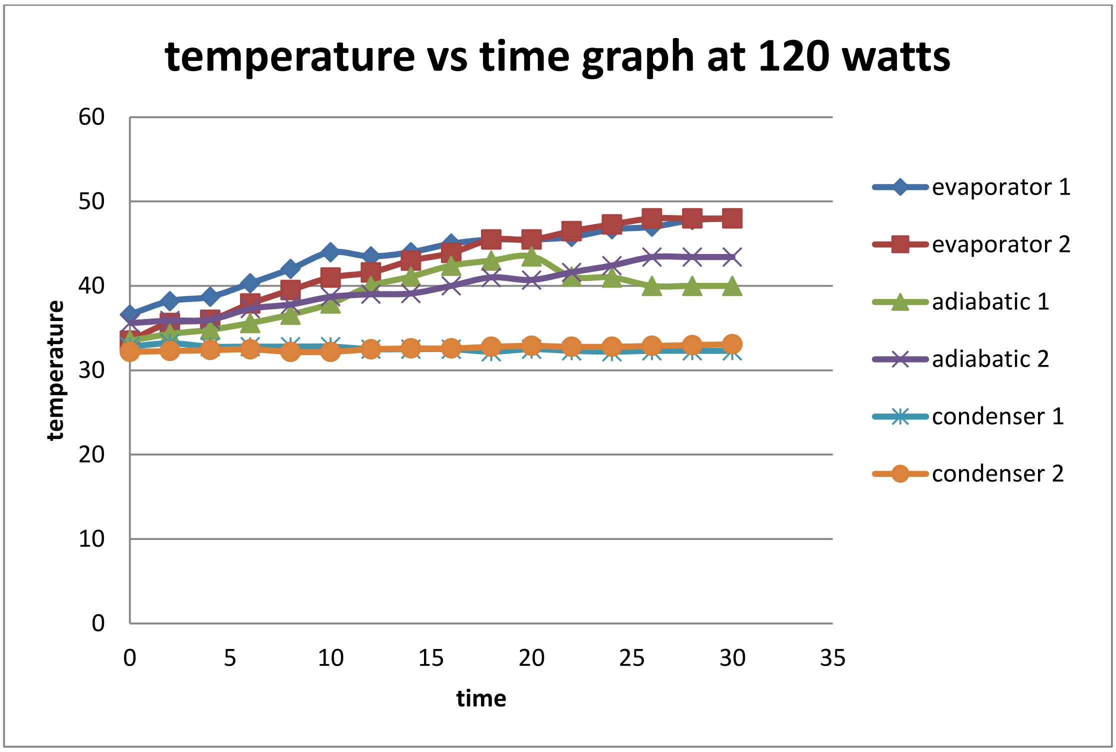

Fig 3.2 temperature variation with time at 120 watts(ethanol)

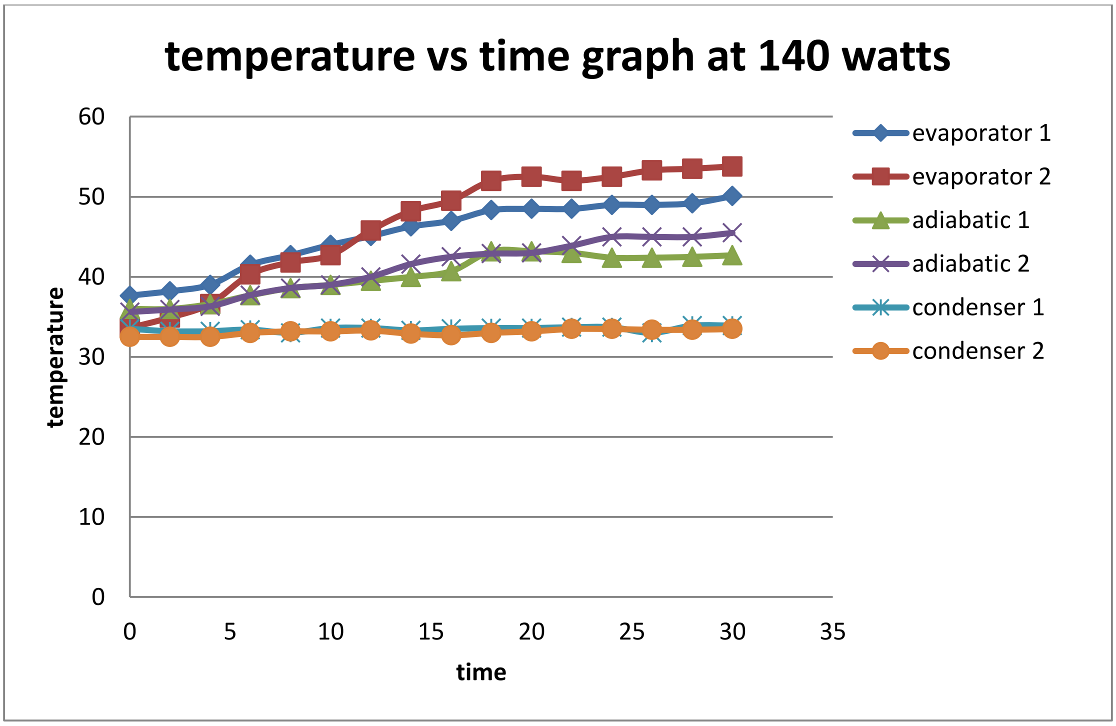

Fig 3.3 temperature variation with time at 140 watts(ethanol)

Thus after completing the experiment on ethanol the copper tube is emptied and distilled water is tested for the same temperature variation with time.

3.4 Results of distilled water as working fluid

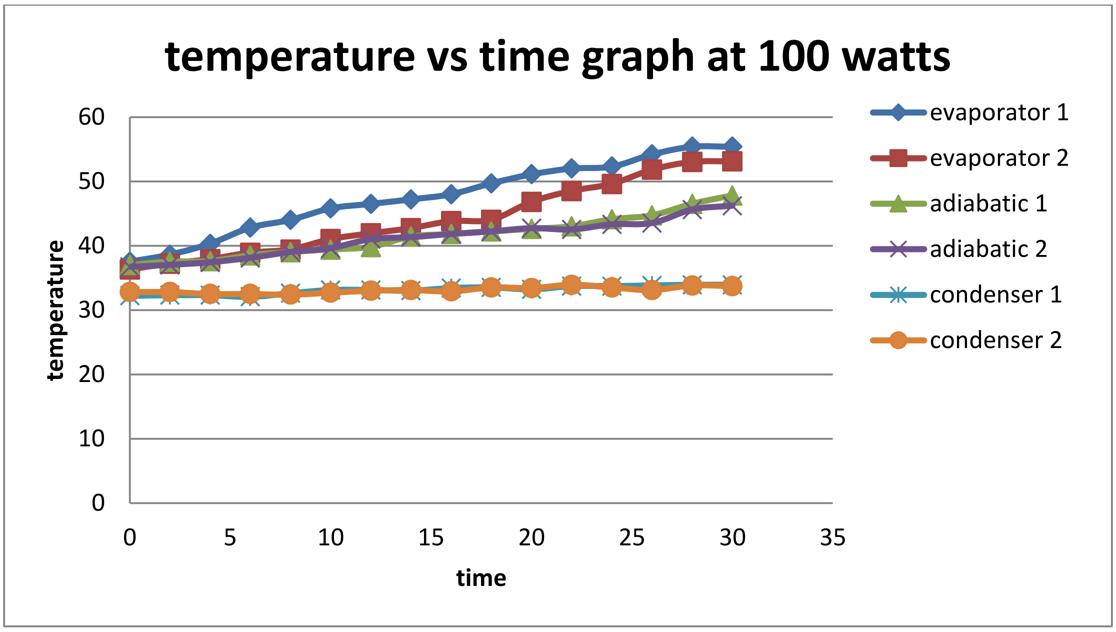

Fig 3.4 temperature variation with time at 100 watts(water)

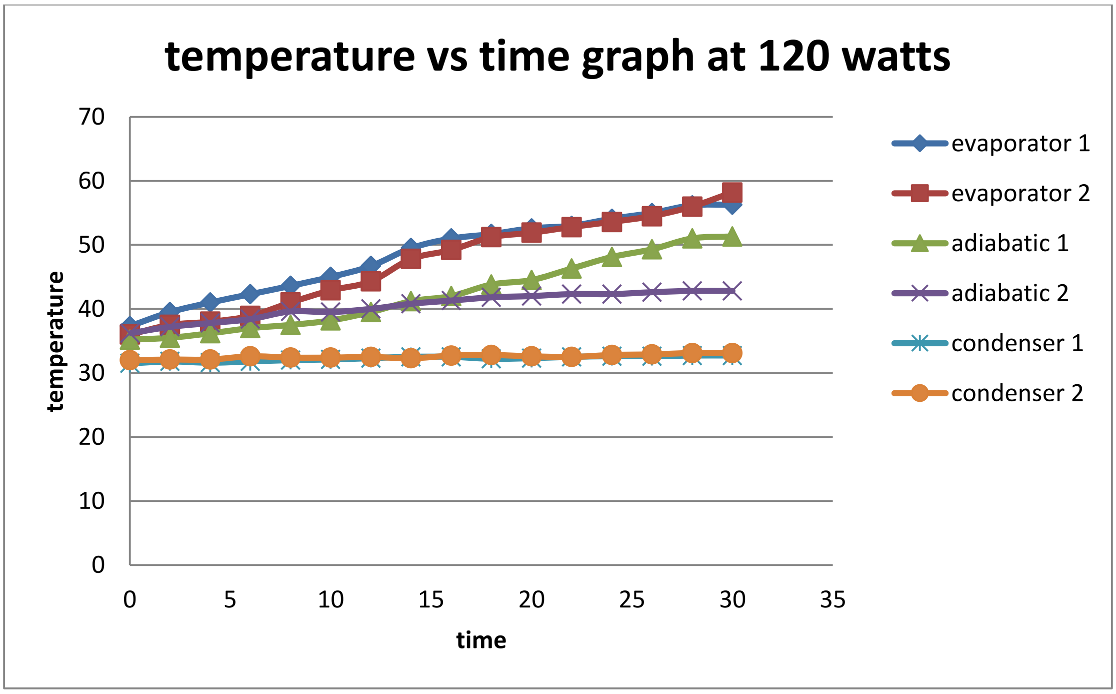

Fig 3.5 temperature variation with time at 120 watts(water)

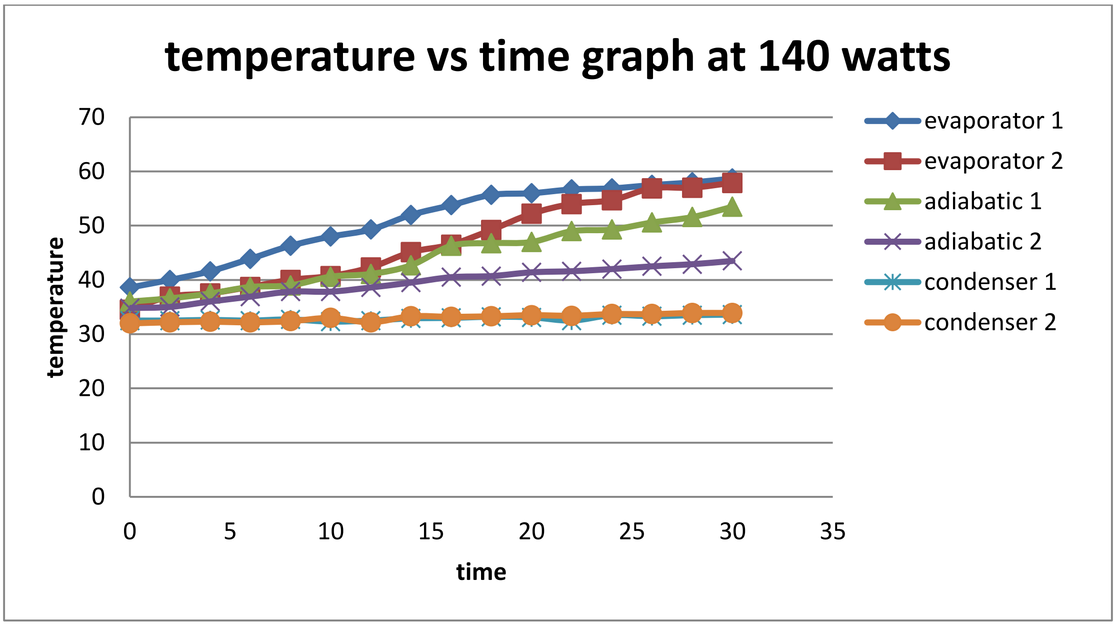

Fig 3.6 temperature variation with time at 140 watts(water)

3.7 Comparison of thermal resistance for ethanol and distilled water at different power input:

Table 3.7 Thermal resistance variation power

power	ethanol (Rth)	water (Rth)
100	0.2	0.22
120	0.125	0.19
140	0.13	0.175

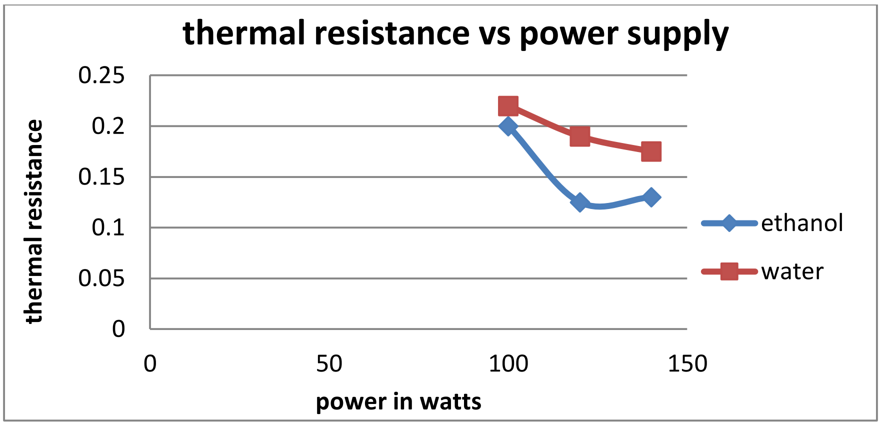

Fig 3.7 thermal resistance variation with power input

3.8 Observations

- From the conducted experiment we observed that the thermal resistance of ethanol at the same power is less than that of thermal resistance of distilled water.
- Also the pulsating action for ethanol occurred at about 49 degrees centigrade where as in the case of water the pulsating action occurred at 51 to 53 degrees centigrade.

4. CONCLUSION

In the present work, the experimental investigation has been carried out on a two looped pulsating heat pipe to predict the thermal performance of the CLPHP with 50% filling ratio. The effects of heat input, temperature variation with time and thermal resistance of ethanol and distilled water are studied.

Following conclusions are drawn from the present experimentation:

- The thermal resistance of distilled water decreases with the increase of heat input from 100 to 140 watts.
- In the case of ethanol the thermal resistance does not follow a particular trend line. We observed that the thermal resistance of ethanol first decreases and then increases from 100 to 140 watts.
- The pulsation of ethanol has been observed to start in the temperature range of 47 to 50 degree centigrade.
- The pulsation of water has been observed to in the temperature range of 50 to 52 degree centigrade.

Finally, it can be concluded that the performance characteristics of ethanol are better than distilled water.

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