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Experimental Investigation of Heat Transfer Performance Characteristics of Closed Loop Pulsating Heat Pipe

Er. Parveen Kumar, Dr. Prinam Anuradha

***Abstract*— Heat transfer is an important term in today's era and there are a lots of devices for high rate of heat transfer, heat pipe is one of them. This research work has a multi-turn Closed Loop Pulsating Heat Pipe (CLPHP) made of copper (I.D. 2 mm, O.D. 4 mm), filled with De-Ionized Water, Methanol and Acetone (respectively) is experimentally studied in vertical position. The study focuses in particular on the effect of heating power of evaporator section, time interval, temperature of condenser section and as well as temperature of evaporator section on the thermal performance (in terms of temperature difference between evaporator section and condenser section and thermal resistance) for Closed Loop Pulsating Heat Pipe (CLPHP) with different working fluids (De-Ionized Water, Methanol and Acetone) by taking fixed filling ratio of 54% and 62%.**

Results show that this CLPHP is sensitive to the used working fluid, heating power and time used. It is concluded that acetone has the best thermal performance among all three working fluids followed by methanol. It is also concluded that time interval (for heating) has great significance on the thermal resistance for all fluids used in this study. With increase in the time interval for heating, thermal resistance also decreases for all fluids. Critical heating power is found to be 65.836 W for de-ionized water, f or methanol 90.24W (for 62% filling ratio) and 65.727 W (for 54% filling ratio) and for acetone 71.136 W, this is due to the fact that thermal resistance starts increasing after regular decrement with respect to heating power. Heating power is also a key parameter which affects the temperature difference (between evaporator temperature and condenser temperature) as applied heating power has been increased this will lead to increase in temperature difference for all fluids.

***Key Words*—Closed Loop Pulsating Heat Pipe, Critical Heating Power, Heat Transfer Performance, Thermal Resistance, Time Interval.**

I. INTRODUCTION

Highlight In last few decades' rapid development in heat releasing equipment's and industries forced researchers to do work on small size effective heat transfer devices for cooling of them. So, the heat transfer is an important term toady's era. Heat transfer describes the exchange of thermal energy, between physical systems depending on the temperature and pressure, by dissipating heat. Heat transfer is directly linked to the term 'Heat', by definition, is the energy in transit due to temperature difference. Whenever exists a temperature difference in a medium or between media, heat flow must. The fundamental modes of heat transfer are conduction or diffusion, convection and radiation. Different types of heat transfer processes are called modes as shown in figure 1.

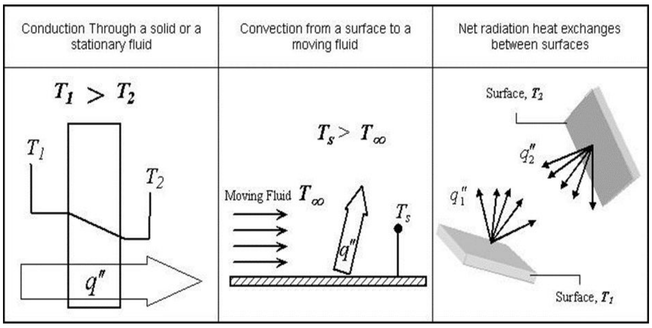

Fig. 1 Modes of Heat Transfer: Conduction, Convection and Radiation

In recent years, the high thermal performance requirements for integrated circuits in computers, telecommunications, networking, and power -semiconductor markets are making high heat flux (> 100W/cm^2) and improved thermal management critical needs. Use of Phase change materials, jet cooling, two phase flow of fluid are the few methods used for cooling purpose. Heat pipes are promising devices to remove thermal energy and keep the integrated circuits at the proper working temperature. Heat pipes are widely used as one of the effective heat transfer devices, researchers are working on different geometries and principle of fluid transport in heat pipes. Heat pipes are one of the most effective procedures to transport thermal energy from one point to another, mostly used for cooling. It is based on a combination of conduction and convective heat transfer, what makes it to a complex heat transfer problem. Heat pipes were developed especially for space applications during the early 60´ by the NASA. One main problem in space applications was to transport the temperature from the inside to the outside, because the heat conduction in a vacuum is very limited. Hence there was a necessity to develop a fast and effective way to transport heat, without having the effect of gravity force. The idea behind is to create a flow field which transports heat energy from one spot to another by means of convection, because convective heat transfer is much faster than heat transfer due to conduction. Nowadays,

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***Er. Parveen Kumar**, Mechanical Engineering Department, UIET, Kurukshetra University Kurukshetra., Ambala City, India, +91-9802845530.*

***Dr. Prinam Anuradha**, Mechanical Engineering Department, UIET, Kurukshetra University Kurukshetra., Kurukshetra, India, +91-9992333226.*

heat pipes are used in several applications, where one has limited space and the necessity of a high heat flux. Of course it is still in use in space applications, but it is also used in heat transfer systems, cooling of computers, cell phones and cooling of solar collectors. Especially for micro applications there is micro heat pipes developed as for cooling the kernel of a cell phone down. Due to limited space in personal computers and the growing computational power, it was necessary to find a new way to cool the processors down.

The heat pipe is a vapor-liquid phase change device that transfers heat from evaporator to the condenser using capillary forces generated by a wick or porous material and a working fluid. Capillary driven two-phase systems offer significant advantages over traditional single-phase systems. Heat pipes are passive devices that transport heat over relatively long distances via the latent heat of vaporization of a working fluid. A heat pipe generally has three sections: an evaporator section, an adiabatic section, and a condenser section.

II. Literature Review

A. Review Stage

In the 1990s, Akachi et al. [1] invented a new type of heat pipe known as the pulsating heat pipe or oscillating heat pipe (PHP or OHP). According to Akachi [1] PHP is " When one end of the bundle of turns of the undulating capillary tube is subjected to high temperature, the working fluid inside temperature increases vapour pressure which causes the bubble in the evaporator zone to grow, this pushes the liquid column towards the low temperature end, the condensation at the low temperature end will further increases the pressure deference between the two ends, because of the interconnection of the tubes, motion of the fluid slug and vapour bubbles at one end section of the tube towards the condenser also leads to the motion of slugs and bubbles in the next section towards the high temperature end. This works as restoring force. The Inter-play between the driving force and restoring force leads to oscillation of the vapour bubbles and liquid slugs in the axial direction. The frequency and amplitude of the oscillation are expected to be depends on the shear flow and mass fraction of the liquid in tube." The most popular applications of PHP are found in electronics cooling because it may be capable of dissipating the high heat fluxes required by next generation electronics. Other proposed applications include using PHPs to preheat air or pump water. This review article will describe the operation of pulsating heat pipes, summarize the research and development over the past decade, and discuss the issues surrounding them that have yet to be resolved. Pulsating heat pipes, like conventional heat pipes, are closed, two-phase systems capable of transporting heat without any additional power input, but they differ from conventional heat pipes in several major ways. A typical PHP is a small meandering tube that is partially filled with a working fluid, as seen in Figure 2. The tube is bent back and forth parallel to itself, and the ends of the tube may be connected to one another in a closed loop, or pinched off and welded shut in an open loop (Figure 2a & 2b). It is generally agreed by researchers that the closed-loop PHP has better heat transfer performance. For this reason, most experimental work is done with closed-loop PHPs. In addition to the oscillatory flow, the working fluid can also be circulated in the closed-loop PHP, resulting in heat transfer enhancement. Although an addition of a check valve (Figure 2c) could improve the heat transfer performance of the PHPs by making the working fluid move in a specific direction, it is difficult and expensive to install these valves. Consequently, the closed-loop PHP without a check valve becomes the most favorable choice for the PHP structures. Recently, PHPs with a sintered metal wick have been prototyped by Zuo et al. [2] and analyzed by Holley and Faghri [3]. The wick should aid in heat transfer and liquid distribution. There has also been some exploration into pulsating heat pipes in which one or both ends are left open without being sealed (Figure 2d)

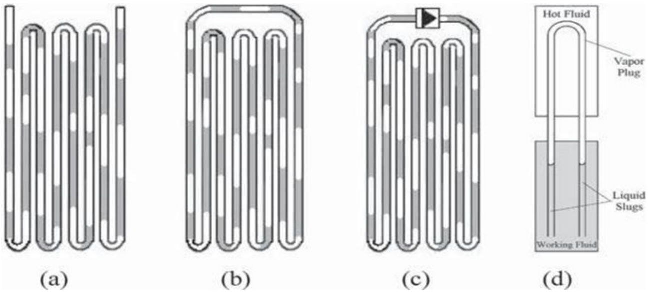

Fig. 2 Different PHPs: (a) open-end, (b) closed-loop, (c) closed-loop with check valve, and (d) PHP with open ends

Zhu et al. (2014) [2] investigated the start-up and heat-transfer performance of a closed-loop pulsating heat pipe with water acetone mixtures (at mixing ratios of 13:1, 4:1, 1:1, 1:4 and 1:13) and pure water and acetone under various filing ratios (35-70%) and heat inputs (10-100 W). The closed-loop pulsating heat pipe was vertically placed and bottom-heated (i.e., heating wires were wrapped on the evaporation section) with inner and outer diameters of 2.0 and 4.0 mm, respectively. It was observed that (1) compared with pure water, the pulsating heat pipe with water acetone mixtures possessed improved start-up performances (2) Under low filling ratios (i.e., 35% and 45%), the pulsating heat pipe with water acetone mixtures presented improved performance against the onset of dry-out conditions compared with PHPs using pure water and acetone. In contrast with the minima of mixtures under certain heat inputs, the maximum thermal resistances of pure water and acetone decreased by 45.8% and 38.7%, respectively.

Holley and Fagri (2005) [3] investigated a means of enhancing heat transfer in a pulsating heat pipe with capillary wick using the model presented here. The model was one-dimensional with slug flow where the momentum equation is solved for each liquid slug. The number and mass of liquid slugs were allowed to vary throughout a simulation. The energy equation was solved both in the wall and wick and in the working fluid. The effects of diameter profile, gravity, fill ratio, and heating and cooling schemes could be studied with the model. Results yield similar trends to what has been experimentally observed. Results also indicate that heat transfer could be enhanced when the diameter of the channel was varied along the channel length, thereby providing increased range of heat load capability, less sensitivity to gravity and in some cases smaller temperature differentials.

Barua at al. (2013) [4] described the heat transfer characteristics of closed loop pulsating heat pipe (CLPHP) which are new entrants in the family of closed passive two phase heat transfer system. It also shows the comparison of thermal efficiency of CLPHP for different filling ratios with two different working fluids, water and ethanol. Experiments are conducted on a CLPHP made of capillary tube of 2.2mm inner diameter. The heat transfer characteristics and the performance of the CLPHP were investigated for filling ratios of 100 %, 82.5%, 62.02%, 41.3% and 28%. The results indicated that the performance of this device changes with the changing of working fluid, filling ratios and heat input and 62.02% filling ratio is optimum.

Wang et al. (2015) [5] investigated the heat transfer performance of a pulsating heat pipe (PHP) charged with deionized water and surfactant solution. The inner diameter of the PHP was 2 mm. The surfactant was sodium stearate, and the concentrations of sodium stearate solutions were 10, 20 and 40 ppm. By that heat transfer performance of the PHP was greatly influenced, and the influence was dependent on the charge ratio and the concentrations of the solutions. Compared with the PHP with deionized water, the thermal resistance and the temperature difference between the evaporation section and condensation section could be decreased by 0.13 K/W and 20.8 K when the charge ratio, the heating power and the concentration of the solution was 54%, 160W and 40 ppm, respectively.

Qu and Ma (2006) [6] theoretically analysed the primary factors affecting the startup characteristics of a pulsating heat pipe. It was found that the wall surface condition, evaporation in the heating section, superheat, bubble growth, and vapour bubbles trapped in cavities at the capillary inner wall affect the startup of oscillating motion in the pulsating heat pipe. When the capillary inner surface was coated or fabricated with cavities or roughness, the pulsating heat pipe could be readily started up. And it was found that the working fluid significantly affects the startup characteristics of a pulsating heat pipe. The results presented here can result in a better understanding of the startup operation of a pulsating heat pipe.

Song and Xu (2009) [7] studied the chaotic behavior of closed loop pulsating heat pipes (PHPs) was. Effect of inclination angles on the chaotic parameters is complex for FC-72 PHPs, but it is certain that correlation dimensions and Kolmogorov entropies are increased with increases in inclination angles. The optimal charge ratios are about 60–70%, at which correlation dimensions and Kolmogorov entropies are high. The higher the heating power, the larger the correlation dimensions and Kolmogorov entropies are. For most runs, large correlation dimensions and Kolmogorov entropies correspond to small thermal resistances, i.e., better thermal performance, except for FC-72 PHPs at small inclination angles of h < 15.

Wang et al. (2009) [8] explored the heat-transport capability of pulsating heat pipes (PHP) working with functional thermal fluids (FS-39E microcapsule fluid and Al2O3 nano-fluid), by comparing them with pure water. The test tube was a four-turn pulsating heat pipe, made of a copper tube with an external diameter of 2.5 mm, and an inner diameter of 1.3 mm. The results show that the heat-transport capability of PHP can be enhanced by using FS-39E microcapsule fluid and Al2O3 nano-fluid as working fluid under specific conditions. When using vertical bottom heat mode, FS-39E microcapsule fluid was the best working fluid and its best concentration is 1 wt %; when using horizontal heat mode, Al2O3 nano-fluid was the best working fluid and its best concentration is 0.1 wt %.

Mehta and Khandekar (2014) [9] studied the performance of Pulsating Heat Pipes (PHPs) requires spatial-temporally coupled, flow and heat transfer information during the self-sustained thermally driven flow of oscillating Taylor bubbles. This study clearly reveals important insights into the PHP operation. Oscillating Taylor bubbles create significant disturbances in their wake which leads to local augmentation of sensible heat transfer. The implications of bubble length, wake characteristics, oscillating frequency and bubble slip velocity on the heat transfer augmentation and, in turn on thermal performance of PHPs can be clearly delineated from this study. The study also brings out the nuances in the estimation of true bubble slip under time varying Taylor bubble flows.

Xu et al. (2005) [10] provided the high speed flow visualization results for the closed loop pulsating heat pipes (PHPs). It was identified that there exists the bulk circulation flow which lasts longer and the local flow direction switch flow. Long vapour plugs were only observed for the methanol PHP, not observed in the water PHP, due to the vapour plug deformation and breakup mechanism, which was analysed in the present paper. Bubble sizes have quasi-fixed distributions versus time over the entire PHP, but have unsymmetrical distributions among various tubes. The complicated combined effects of bubble nucleation, coalescence and condensation are responsible for the oscillation flow in PHP.

Kwon and Kim (2015) [11] investigated the effect of a dual-diameter channel on the flow and heat transfer characteristics of flat plate micro pulsating heat pipes (MPHPs). Using MEMS techniques, the MPHPs were fabricated: rectangular channels with dual hydraulic diameters were engraved on a silicon wafer to form a meandering closed loop with 5 turns. The Pyrex glass was used as a cover which enables flow visualization in the MPHP. Experimental results show that the MPHPs with a dual-diameter channel can operate stably even in a horizontal position and have uniform thermal performance regardless of the orientation when a proper condition is met. According to experimental data, the figure of merit has to be larger than 2×10^5 for orientation-independent operation of the MPHP.

Aboutalebi et al. (2013) [12] investigated experimentally the effect of rotational speed on thermal performance of a RCLPHP. The research was carried out by changing input power (from 25 W to 100 W, with 15 W steps) and filling ratio (25%, 50%, and 75%) for different rotational speeds (from 50 rpm to 800 rpm with an increment of 125 rpm). The results presented that at a fixed filling ratio, thermal resistance of RCLPHP decreased with increasing heat input applied to evaporator. Above a certain range of heat input, probability of partial dry-out of evaporator existed, which led into thermal performance deterioration of RCLPHP. Moreover, thermal resistance of RCLPHP decreased with increasing rotational speed and probability of partial dry-out in the evaporating section reached to its least amount.

Arab et al. (2012) [13] investigates the application of pulsating heat pipes (PHPs) as a heat transfer tool in a solar water heater (SWH). Four different tests are carried out; SWH with thermosiphon cycle, SWH with PHP filling ratio (FR) = 30%, FR = 50% and FR = 70%. The results show that PHP with FR = 70% has the most stable and the longest functioning duration. While mean temperature of container water was 35.3 _C and 34.5 _C for thermosiphon cycle and

PHP FR = 70%, respectively, the surface area under the container water temperature curve vs. time for thermosiphon is 87.69% of that of PHP FR = 70% which indicates the higher heat transfer rate for the ELPHPs. In addition, calculations show efficiency of PHP FR = 70% is equal to 53.79% while efficiency of thermosiphon mode was in range of 31% and 36%.

Teseng et al. (2014) [14] investigated the effect of uniform and alternating tube diameter on the performance. The working fluids include distilled water, methanol and HFE-7100. Tests are performed with both horizontal and vertical arrangement. Normally the thermal resistance is decreased with the rise of heat input, and reveals a minimum value at a certain heat input followed by shows a marginal rise when the heat input is increased further. Both uniform and alternating design reveals the similar trend. For the vertical arrangement, the thermal resistance is much lower than that in horizontal arrangement. For a low input power, CLPHP with HFE-7100 shows the least thermal resistance. By contrast, CLPHP with distilled water shows the smallest thermal resistance when the input power is increased over 60 W.

Mameli et al. (2014) [15] investigated a multi-turn Closed Loop Pulsating Heat Pipe (CLPHP) made of copper (I.D. 1.1 mm, O.D. 2 mm), filled with FC-72 on the combined effect of the inclination angle (gravity) and the filling ratio at different heat input levels on the device operation stability and the thermal performances. Results show that this CLPHP is very much sensitive to the gravity head and that the vertical operation is affected by unstable operation at high heat input levels. On the other hand the CLPHP in the horizontal position is less efficient, but it does not undergo any performance drop with respect to the heat input level until the maximum heat input level is reached. This behavior was confirmed at different filling ratios, and the optimal one is 0.5.

III. EXPERIMENTAL SETUP

The experimental setup consists of a Control Panel with connected duct containing vapour compression refrigeration system inside it and a separate heating arrangement below the duct exactly in line with the hole provided into the duct for placing CLPHP. The main frame (duct) is so designed that it contains an inherent housing for a complete vapour compression refrigeration system (containing compressor, cooling coil, condenser coil, cooling box having space for glycol solution for better cooling in condenser section), insulation from outer environment and holding arrangements for CLPHP. A connected arrangement is also designed for control panel having temperature indicators, display panel with voltmeter and ammeter and voltage variac. The separate heating arrangement was designed similar to oven provided space for entering the CLPHP as per the requirements.

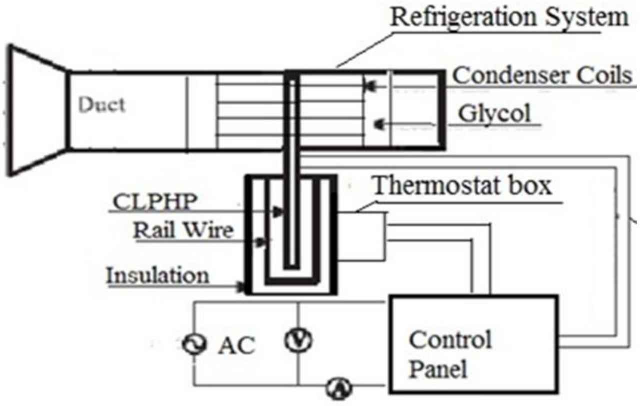

Fig. 3 Line Diagram of Experimental Setup

1. Compressor
2. Condenser
3. Cooling Section
4. Heating Section
5. Control Panel
6. Duct Housing
7. Insulation

Fig. 4 Experimental Setup

After that, a CLPHP was fabricated by using capillary of copper (inner diameter of 2 mm and outer diameter of 4 mm) turned into a frame having number of length and breadth of 290 mm and 220 mm respectively. For sensing the temperature of different sections and positions on CLPHP and temperature of vapour compression refrigeration system and heater six open source sensors or, chip sensors and two Resistance Temperature Detectors (RTDs) were used respectively mounted on the various locations. Line diagram and photographic diagram are shown in figure 3 and 4 respectively.

IV. EXPERIMENTATION

In the present research work, the methodology used was purely based upon the experimentally in which some of the parameters kept fixed and other were varied with respect to the desired objectives. Filling ratio have been kept constant for this research work, as there were many researchers who already find out the optimal value for this. Therefore, parameters which was kept fixed (other than specification of CLPHP) in whole experimental study was given as:

Filling Ratio of working Fluid = 62% and 54% of the volume of the CLPHP (approx. 3.78 ml and 3.30 ml respectively.), Length of Condenser Section = 120 mm. Length of Adiabatic Section = 76 mm, Length of Evaporator Section = 94 mm.

By keeping constant above stated parameters, there were certain parameters which has been varied given as follows: Heating Power (Q) initial from 5 W upto 200 W (depending upon the properties of working fluid), Time Interval (t, in minutes), Temperature of condenser section (C.S., in C), Temperature of evaporator section (E.S., in C), Thermal

Resistance (Rt), Working Fluid. (De-ionized Water, Methanol, Acetone and Ethyl Acetate)

Experimental Procedure: before starting any experiments, CLPHP was filled with the working fluid with the help of compressor by using burette upto 62% of its volume (3.78 ml) and in next experiment 54% (3.30 ml) for same experiment by changing filling ration percentage. After ensuring the voltage variac should be set at initial value (near about zero) and CLPHP placed into the space provided for it should be properly insulated from outer environment. The cooling system's switch was put on by keeping heater switch off. This is done because, cooling system takes much time to lowering the condenser temperature. Initially, all readings were noted down as starting the compressor of cooling system. After that, voltage was varied starting from 17 volts (having results into 5 Watt Heating Power, Q) as the heater switch put on time also noted down with respect to the ammeter current in Ampere and all temperatures. The Heating Power was set to a particular value and varied after a gap of 2 minutes (or, 120 seconds. All readings have been recorded after a particular time periods and these all steps were repeated again and again by changing the Heating Power and voltage. Temperature of Condenser Section (C.S.) and Evaporator Sections (E.S.) was tried to maintain after performing each experiments and all readings was recorded instantly while switching to the next experiments.

The same procedure were followed by using different working fluid inside the CLPHP (ensuring that previous fluid should be taken out completely.

V. RESULTS AND DISCUSSIONS

A. *Effect of Time Interval on Thermal Resistance*

Effect of time interval on thermal resistance is presented in figure 5 for two filling ratios (62% and 54%). It has been observed from the figure that initially, the thermal resistance is very high which means that heat transfer is poor. During start-up period a sharp decrease in thermal resistance is noted for first six minutes. This is due to the fact that the thermal resistance is inversely proportional to the heating power. Further, a slight increase in thermal resistance has been observed with increase in time interval and similar trend has been observed for the both filling values.

Critical heating power for this fluid observed is 65.836 W, as the thermal resistance changes its behavior (starts increases after regular decrement.)

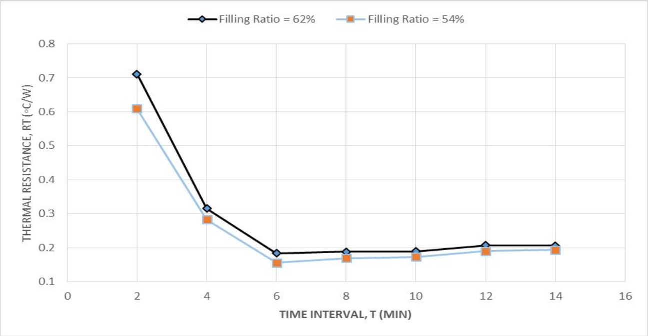

Fig. 5 Variation of Thermal Resistance w.r.t Time Interval (D.I. Water)

For Methanol, It has been observed from the figure 6, that initially, the thermal resistance is very high which means that heat transfer is poor. During start-up period a sharp decrease in thermal resistance is noted for first eight minutes and for filling ratio 62% it decrease up to first ten minutes. This is due to the fact that the thermal resistance is inversely proportional to the heating power. Further, an increase in thermal resistance has been observed with increase in time interval and similar trend has been observed for the both filling values.

Critical heating power for this fluid observed is 90.24W (for 62% filling ratio) and 65.727 W (for 54% filling ratio), as the thermal resistance changes its behavior (starts increases after regular decrement.)

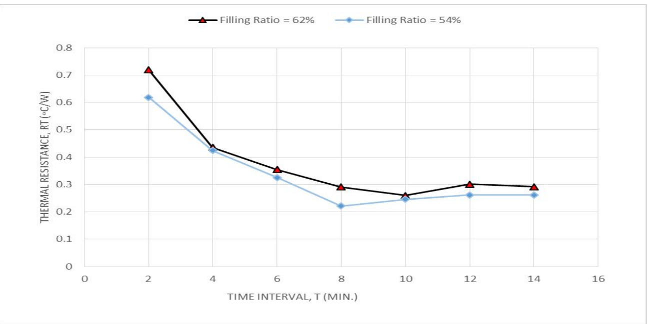

Fig. 6 Variation of Thermal Resistance w.r.t Time Interval (Methanol)

Effect of time interval on thermal resistance for Acetone in figure 5.5 for two filling ratios (62% and 54%) has been presented. It has been observed from the figure that initially, the thermal resistance is very high which means that heat transfer is poor. In this fluid, the thermal resistance continuously decreases with increase in time interval for evaporator section. Similar trend has been observed for the both filling values.

Critical heating power for this fluid observed is 71.136 W, as the thermal resistance changes its behavior (starts increases after regular decrement.)

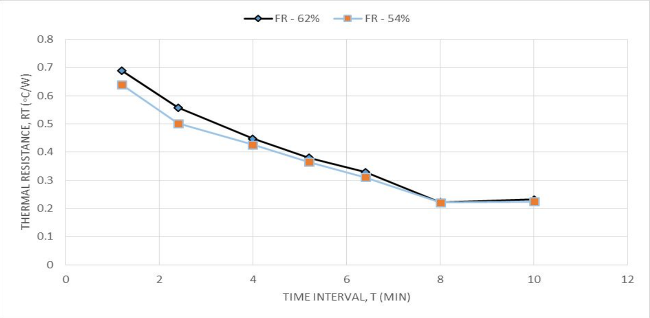

Fig. 7 Variation of Thermal Resistance w.r.t Time Interval (Acetone)

B. *Effect of Heating Power on Temperature Difference*

Heating Power effects on temperature difference has been

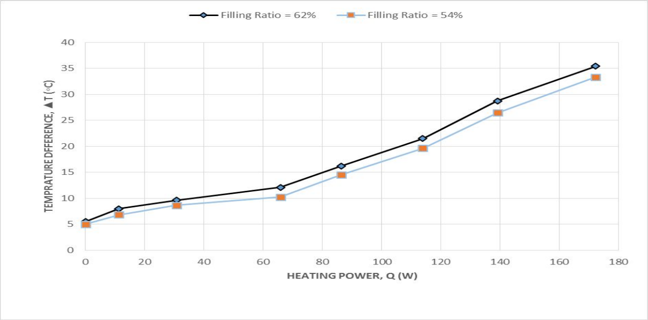

Fig. 8 Variation of Temperature Difference w.r.t. Heating Power (D.I. Water)

represented in figure 8 for the same filling ratios (62% and 54%). It has been observed from the figure that temperature difference increases slowly by increase in heating for evaporator section, this is due to the fact that initially thermal resistance decreases which will results into lesser temperature difference. Further, temperature difference increasingly with more variation with increase in heating power. Similar trend has been observed for the both filling ratio.

Effect of heating power on temperature difference has been represented in figure 9 for the same filling ratios (62% and 54%). It has been observed from the figure that temperature difference increases with heating power, but slowly increases in starting with increase in heating power of evaporator section, this is due to the fact that initially thermal resistance decreases which will results into lesser temperature difference. Further, temperature difference increasingly with more variation with increase in heating power. Trend for the both filling values are mostly similar. After that the value of temperature difference started increasing by increasing heating power with time up to fluid dry out temperature limit.

In last, effect of heating power on temperature difference has been represented in figure 10 for the same filling ratios (62% and 54%). It has been observed from the figure that initially, temperature difference has been negligible means condenser section and evaporator sections have near about same temperatures, after that it is slowly increases up to 22.4 W for the 54% filling ratio and then sharply increases for the next value, but in case of 62% filling ration, the temperature difference has been increasingly properly up to 47.244 W as shown by the 62% filling ratio and then shows the same temperature difference, cleared from the graph as shown in the next page. Further, the value of temperature difference started increasing by increasing heating power with time up to fluid dry out temperature limit.

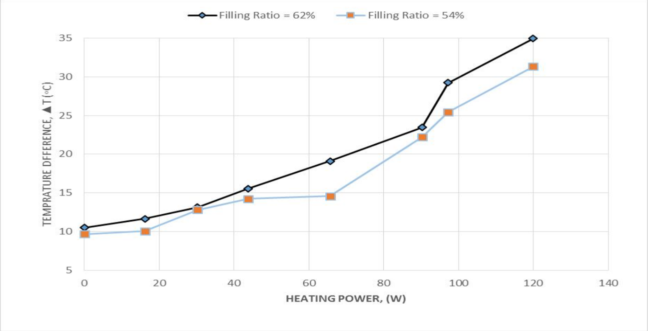

Fig. 9 Variation of Temperature Difference w.r.t. Heating Power (Methanol)

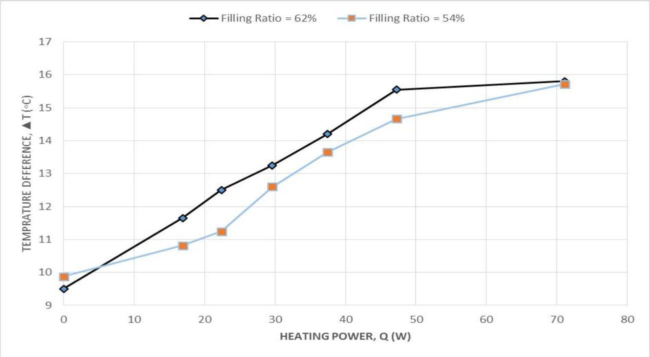

Fig. 10 Variation of Temperature Difference w.r.t. Heating Power (Acetone)

VI. CONCLUSIONS

The important conclusions drawn from this investigation are summarized. As from the graphs, it has been concluded that time interval (for heating) has great significance on the thermal resistance for all fluids used in this study. With increase in the time interval for heating, thermal resistance decreases sharply in first 6 minutes then, it shows negligible changes for De-ionized Water. For Methanol, thermal Resistance also decreases sharply in the first 8 minutes, after that it starts increasing with small variations in it. Acetone shows the continuous decrement in the thermal resistance with respect to increase in the time interval of heating.

Heating Power is also a key parameter which effects the temperature difference (between evaporator temperature and condenser temperature) as applied heating power has been increased this will lead to increase in temperature difference for all fluids.

Acetone is found to have better thermal performance with respect to time interval and heating power among all the three working fluids followed by methanol.

Critical Heating Power noted is 65.836 W for deionized water, for methanol 90.24W (for 62% filling ratio) and 65.727 W (for 54% filling ratio) and for acetone 71.136 W, as thermal resistance starts increasing after regular decrement with respect to heating power.

There have been certain work which can be achieved in future like, enhancement in thermal performance of CLPHP can be done by using more variables such as diameter of CLPHP, number of turns, length of various sections, different working fluids, filling ratio of working fluids etc. Critical diameter can also be calculated for CLPHP. Insulating behavior can be studied with the help of CFD modelling

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Er. Parveen Kumar, Mechanical Engineering Department, UIET, Kurukshetra University Kurukshetra., Ambala City, India, +91-9802845530.

Dr. Prinam Anuradha, Mechanical Engineering Department, UIET, Kurukshetra University Kurukshetra., Kurukshetra, India, +91-9992333226.