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Effect of Ethanol based Mixtures on the Performance of CLPHP–Experimental Approach

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ABSTRACT: Day by Day the demand is increasing for micro and effective heat transfer devices. The thermal management of these devices is complex. Applications like electronic cooling, solar heat recovery, heat exchangers etc. requires a device to handle higher heat flux rates. Pulsating Heat Pipe (PHP) which involves a multi-phase heat transfer is one such device, popular for handling such a higher heat fluxes rates. The present paper describes the experimental work carried out on an 8 turn closed loop pulsating heat pipe for different ethanol based working fluid mixtures, viz., Ethanol with Water, Methanol and Acetone. The most important aspect to consider is how the performance is affected with inclinations at different fill ratios. Parametric analysis is performed for different fill ratios of 50%, 60% and 75% with supplying heat of 20 to 100W. The heat input value is depending on the fluid mixture boiling points. In the performance behaviour of CLPHP the gravity force plays very important role. The performance parameters of CLPHP i.e. number of turns and heat supplied at evaporator also effects gravity force and hence inclination on the performance of CLPHP. For CLPHP to operate at different inclination positions, viz., 0-degree, 45-degree and 90-degrees, the setup is mounted by using nut and bolt arrangement. At various heat inputs the variation of thermal resistance are plotted for all the working fluids mixtures considered. At all the inclinations and fill ratios gradual decrease in thermal resistance takes place with increase of heat supply. Among all ethanol based mixtures ethanol acetone shows least resistance and the best performance.

Keywords: Closed loop pulsating Heat pipe (CLPHP), Fill ratio, Inclination angle, Mixtures, Thermal resistance, Working fluid.

Abbreviations: CLPHP, Closed loop pulsating heat pipe; PHP, Pulsating heat pipe; Rth, Thermal resistance.

Nomenclature: Te-Average evaporator temperature, Tc-Average condenser temperature, Q-heat input, Rth-Thermal resistance, Di-Inner diameter, D0-outer diameter, FR-Fill ratio

I. INTRODUCTION

The advancement of new two phase heat transfer devices are in major demand at present industry due to its less cost and high heat transfer capability. Closed loop pulsating heat pipe (CLPHP) is one of the most promising and novel device which is mainly suitable for applications that involves high heat transfer rates. Akachi (1993) proposed and patented CLPHP. It is a capillary tube bent into number of turns in serpentine manner end-to-end connected with three sections Evaporator (source) at bottom, Adiabatic and Condenser (sink) at the top portion as shown in the fig [1]. The working fluid is partially filled in a tube. Evacuation of tubes takes place before filling the fluid. This results in liquid slugs and plugs of fluid flow alternately. Once the heat power is supplied at evaporator section of CLPHP, the liquid starts evaporating by forming a thin liquid film surrounded to each vapour plugs and forming bubbles.

In the condenser, condensation occurs due to the fluid when it is pushed towards condenser section. This liquid slugs and plugs causes pressure instabilities which results heat transfer in the tubes. In Vapour plugs the transfer of heat takes place through latent heat whereas in liquid slugs it is due to sensible heat [2].

II. LITERATURE REVIEW

Nekrashevych and Nikolayev (2019) discussed numerical simulations of 10-turn copper made CLPHP with water as working fluid under different orientations such as horizontal, vertical (top-heated) and vertical (bottom-heated) orientations [3].

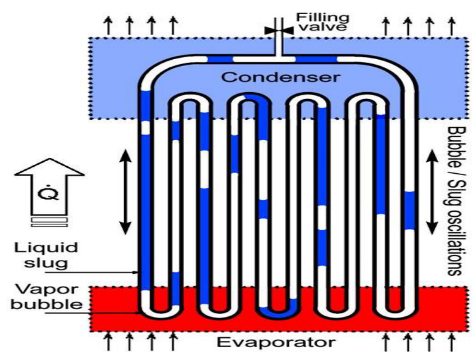


Fig. 1. Schematic of closed loop pulsating heat pipe [16].

Horizontal orientations almost exhibit similar performance as in microgravity conditions. By using CASCO software simulation studies have been done. The results show that the gravity influences the liquids lugs formed inside the PHP. Results shows, the continuous and start up phenomena occurs inside the PHP. For all heat loads continuous oscillations are observed under vertical orientation whereas up to a threshold power only oscillations are continuous in the horizontal orientation. Upon reaching the threshold value of heat input dry out is observed. The performance of PHP at different orientations is also given with respect to phase distribution in terms of latent and sensible heat transfers. In all the oscillation regimes the heat exchange in the PHP is influenced by phase change phenomena. Presence of liquid plugs and liquid films inside the evaporator helps to control the latent and sensible heat rates. Simulations data is in good agreement with experimental data as the major portion of transferred heat is latent heat for the efficient working of PHP. Md. Rahman *et al*., (2016) analysed thermal performance of a CLPHP of 8 turns experimentally without and with fins incorporated at cooling section by using water and acetone pure fluids as working fluids [4]. Fill ratios are varied from 40% to 70% in steps of 10% and the inclinations angles such as 0°, 30°, 45° and 60° at various heat inputs from 10 to 100W insteps of 10 W are implemented. Results shows that at lower heat input values rapid decrease in thermal resistance occurs and performance of PHP is more sensitive to the inclination angle whereas at higher inputs slow reduction in thermal resistance is observed and at this condition PHP dependency on inclination angle is less. Performance wise Fin structure PHP is good with that of without fin. This is due to heat transfer enhancement at condenser is from both the sides. For acetone the evaporator and condenser sections temperature difference is observed as high with fin structure with that of without fin structure. This results in thermal resistances obtained without fin structure are observed as high compared to with fin structures. For working fluid Acetone at high fill ratios and heat inputs dry out is observed. This is due to quick collapse of vapour bubbles at condenser section with fin arrangement .To compensate the loss of liquid through vaporization rapid movement of liquid slug takes place from condenser to evaporator. Results also show that upon increase of inclination angle, there is increase in thermal resistance. Hudakorn *et al*., (2008) observed the overall performance of 10 turn oscillating heat pipe made up of Pyrex Glass tube with dimensions 1 mm and 5 mm diameters respectively [5]. The geometry was considered such a way that all the three sections are in same dimensions. R123 as working fluid with 50 % fill ratio was selected. Due to insufficient condensed liquid film in the horizontal orientation there occurs dry-out. As the angle was increased from horizontal to all the way to vertical due to flooding of evaporator performance limit occurred. The same experiment is repeated by changing the tube material, increasing evaporator length and diameters of tubes with ethanol and water as working fluids. Inside the tube the vapour bubble formed is longer and the insufficient liquid in evaporator results dry out. With the controlled vapour temperature and by increasing inner diameter as evaporator length increases the critical heat flux decreases for all the inclinations angles. The results show that performance is better with copper heat pipe compared to Pyrex glass. Xue and Qu (2014) performed experiments on pulsating heat pipe of 6 turn quartz glass with 2mm and 6mm inner and outer diameters respectively [6]. Ammonia as Working fluid and the 50 % filling ratio was selected. Heat input is varied from 40W to 280W with a step of 40W. From the visualisation of flow oscillations quick movement of fluid from heating to cooling section is observed. At low heat input power easy start up and hard circulation takes place. The direction of circulation is always changes in both clock wise and anti -clock wise directions. At the horizontal operation burnt out occurs as the power heat input is increased in evaporator section. The tubes are in shortage of fluid. It is observed that all the liquid try to accumulate at condenser where the pressure is very low, so there is no heat transfer from heating to cooler section due to gravity. This lead to worse thermal performance of PHP. Also concluded that this can be improved upon changing the fill ratio from 50 % to higher values. Patel and Mehta (2016) discussed the performance of 9 turn CLPHP of 2mm and 4mm ID/OD with water as working fluid with 50% operating conditions with heat input supply of 10-50 Watt [7]. They also investigated gravitational effect by placing evaporator at 180º, 0º, 90º, 45º and inclined 135º orientations. Results says that at lower heat inputs no pulsation is observed as heat is not transferred from evaporator to condenser. Accumulation of heat takes place at evaporator. In the case of higher heat inputs liquid slugs and vapour plugs are moved from evaporator to condenser and transfer of heat also takes place. The temperature difference also less at this range leads to lower thermal resistance and better performance of PHP. With respect to orientation this trend is not observed, there is no pulsation observed at 135 and 180 degree orientations. While in case of vertical bottom (0°) pulsation is observed in all the tubes. To return the fluid in the form of liquid slugs to evaporator section from condenser section gravity plays the role. At 90 degree position also pulsation occurs but the results shows 0 degree gives minimum resistance and that of 90 degree gives maximum resistance whereas 45 degrees gives in-between performance. Goshayesh *et al*., (2015) investigated on copper PHP with 1.25 and 3 mm ID/OD and Fe_2O_3 nanoparticles was added to the kerosene as the working fluid [8]. By taking 50% fill ratio heat is supplied from 15W-90W for different orientations such as 0°, 15°, 30°, 45°, 60°, 75°, 90° and concluded that magnetic field causes reduction the thermal resistance of tube due the addition of nano particles. The heat transfer rate is increase to 16 % at vertical positions. When operating horizontally there was no movement of vapour bubbles. Normal PHP operation is observed at 60° and 75° inclinations. Ayel *et al*., (2010) presented the influence of working fluid and slope on CLPHP [9]. An experimental setup consists of copper tube with 1.2 mm and 40 turns while the other with 2.5mm and 20 turns were developed. Acetone, Ethanol, pentane and water are considered as working fluids in horizontal and vertical positions. The cold source temperature was maintained from 20 to 80ºC. By tilting the PHP in favourable inclination thermal resistance generally decreases with increasing heat flow in the evaporator. An abrupt change in the transition from the horizontal to the vertical position occurs. Paudel and Michna (2014) investigated a 20-turn PHP with 1.6 mm inner diameter copper tubing in both vertical and horizontal positions with 70% fill ratio of water as working fluid [10]. The pressure variations were observed at 16 W power for vertical 90° orientation. This is generally preferred as it had heater input to induce the start of pulsation and thus reduce the thermal resistance and concluded that thermal resistance was slightly higher than vertical for 60°, 45° and 30° orientations. Until a higher heat input power applied the pulsation did not started for these orientations and very large heat inputs are required for horizontal orientation. To determine the conduction heat transfer one dimensional conduction analysis is carried out through tubing to condenser section. Curve fitting relation was drawn to relate the heat loss to the heater section and ambient temperature difference. Jahan *et al.,* (2013) investigated by conducting experiments on

CLPHP of 13 turns for performance characterisation with ethanol and water as working fluids operating at 70% fill ratio with an inclination angle 0°, 30°, 45°, 60°, 75° and 90° (horizontal) [11]. The length of CLPHP considered was148 cm with 2mm and 3mm capillary dimensions. Results concluded that the temperature variation with heat input first increases rapidly and is varies for different regions. The increase in temperature slowly reduces in evaporator due to the heat required in phase transfer after reaching the boiling point of fluid. In condenser section also the temperature slowly reduces till it becomes close to room temperature. This leads to adding additional device at condenser section. The effectiveness of CLPHP explained clearly with factor thermal resistance. In the system it indicates the amount of resistance that heat experiences. The fall of thermal resistance slowly falls is not same in all the cases; it varies in the inclined mode. In the experimentation they investigated the effect of heat flux in vertical orientation and observed as the size of the vapour bubble increases in the evaporator as it takes up heat. The bubbles will rise up due to their own buoyancy force and the liquid slugs present in between travel along with these vapour bubbles in the tube. In case of horizontal direction very less movement of vapour bubbles was observed. As gravity is ineffective in this direction only pressure forces due to temperature difference is only force for the movement of liquid slugs and plugs. Lee *et al.,* (1999) done experiments on a brass tube multi turn PHP with ethanol as working fluid for different orientations [12]. Results shows that for a fill ratio of 40-60% the active bubbles were observed and in the range of 30-degree to 90-degree PHP gives good performance results The PHP performance is mainly depend upon various geometrical and operational parameters. The fluids with lower values of latent heat will propagate oscillatory motion. The bubble formation is easily observed for those fluids. Cai *et al*., (2002) conducted experiments and concluded that selection of working fluid is mainly depends upon properties like surface tension, density latent heat and viscosity [13]. For PHP configuration the performance parameters like number of turns, filling ratio and are considered. Inclination angle effects pulsating heat pipe performance with number of turns. Upto 40 number of turns PHP having inclination effect beyond this number inclinations doesn't have any effect on performance of PHP .Among all the factors the selection of working fluid is the challenging one along with orientation as many fluids fall under the operating range. Barua *et al*., (2013) conducted experiments with water and ethanol as working fluids in a CLPHP with 2.2 mm inner diameter tube bent into U shape with 3 turns at five different filling ratios and concluded that between 0 and 25 W heating power ethanol at 80% and water at 70% fill ratio represented better heat transfer performance [14]. Yang *et al*. (2008) had observed that the PHP with 2 mm diameter was found to be better than that of 1 mm diameter because the thermal resistance values. Conducted experiment on 40 turns with two different diameters PHP. Experimental results shows that compared to the 2mm diameter tube PHP with 1 mm inner diameter achieves very high axial and radial heat flux values [15].
The fluids are tabulated with its thermo physical properties.

Table 1: Working fluids and its properties.

Working fluid	Boiling point (ºC)	h_{fg} (KJ/Kg)	ρ(vapour) (kg/m^3)	ρ (liquid) (kg/m^3)	σ (10^{-3} N/m)	Cp (liquid) KJ/Kg-K	Cp (vapour) KJ/Kg-K
Acetone	56.2	520.56	2.123	748.5	19.09	2.28	1.385
Ethanol	78.3	962.45	1.372	758.1	17.46	0.73	1.604
Methanol	64.7	1119.59	0.566	750.8	18.87	2.52	1.601
Water	100	2251.0	0.597	958.7	58.91	4.22	2.034

In the present experimentation the heat transfer performance of closed loop pulsating heat pipe of 8 turns is charged with ethanol based mixtures was analysed. The experiments are carried out on Ethanol with Water, Methanol and Acetone mixtures. The Orientations 0º, 45º and 90º inclinations at fill ratios of 50, 60 and 75% are considered.

III. DESCRIPTION OF SETUP

The 8 turn CLPHP is designed and fabricated for the present experimentation is shown in Fig. 2.
CLPHP is made up of copper tube bent in serpentine manner of 8 U-turns in the evaporator and condenser sections. To set the dominance of surface tension force over gravitational force the inner diameter of copper tube was selected less than critical diameter of CLPHP [9]. CLPHP consists of evaporator, adiabatic and condenser sections with lengths 42mm, 170 mm and 52 mm respectively. Evaporator section is of size, 330*55*90 mm, while Condenser section is of size, 320*55*95 mm. In order to avoid the heat loss to the atmosphere a thick layer of insulating material was wrapped around the evaporator block. To prevent heat loss from the adiabatic section, it is also fully covered with glass wool. Copper tube of length 264 mm was folded to obtain 16 parallel channels and 8 tube bends.

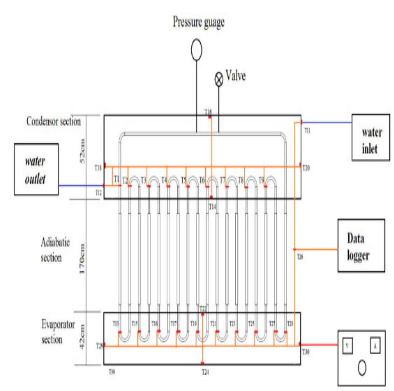


Fig. 2. Schematic diagram of experimental 8 turn CLPHP [16].

The PHP is then closed end to end to make a closed circuit by means of T-joints. Two non-return valves were provided to the outer copper tube. One valve was connected to the vacuum pump other valve was used for filling and removal of working fluid. A reciprocating vacuum pump was connected to the filling valve to create vacuum in side PHP.

IV. INSTRUMENTATION

A pressure transducer is provided at the condenser section. The CLPHP was equipped with 30 thermocouples Among them 9 thermocouples are placed on the condenser tubes, 10 thermocouples are located on the evaporator tubes and four thermocouples each are placed on the 4 sides of condenser and evaporator boxes respectively in order to maximise the thermal contact. One thermocouple was placed such a way to measure the ambient temperature. Heat input to the evaporator was controlled through control panel. It consists of digital voltmeter and ammeter. To record temperature data for every 5 seconds the temperature scanner with data acquisition system was used for all thermocouples. Condenser section was cooled by water jacket from a cold bath. Thermocouples are provided to measure inlet and outlet temperature of water from water jacket.

V. EXPERIMENTAL PROCEDURE

With all the required equipment procurement, the setup is fabricated. Once the fabrication is done experiment has been carried out. The experiment was carried out for three different fluid mixtures and three different inclinations at three different fill ratios of heat pipe. The fluid is injected by using syringe in to the pipe for every inclination position for the required fill ratio. The setup was first placed in vertical 0-degree inclination position and heat input was supplied at evaporator section. For all the working fluids, the experiments are carried out by varying heat input between 20 to 100 watts by using variac. From working fluid to fluid the heat input supplied varies depending upon the operating temperature limit. From low value to high value the heat input was stepwise increased during the experimentation. The temperatures of different sections of CLPHP were recorded by using data logger system. For every 5 seconds the temperature data was recorded. This procedure is repeated for each fill ratio of 50%, 60% and 75% and for each inclination angle considered. Convection mode of heat transfer takes place in condenser. A cooling jacket is provided for cooling the condenser. The difference in average temperatures of evaporator and condenser were obtained. The performance parameter thermal resistance was calculated for all the fluid mixtures during the investigations. This resistance indicates the performance of system. The system exhibits higher efficiency when low resistance to heat flow occurs i.e. lower value of thermal resistance. The results and discussions are made on the basis of different characteristics that influence performance of CLPHP. The procedure is repeated for all the considered fill ratios by changing the positions. For all the fluid mixtures considered the above procedure was carried out systematically.

VI. RESULTS AND DISCUSSIONS

Variation of thermal resistance: The ratio of difference of evaporator and condenser average temperature to its heat input at that time is defined as thermal resistance. Mathematically can be expressed as

$$Rth = \frac{(Te - Tc)}{Q} \qquad (1)$$

where, Q=heat input in Watts,

$(Te - Tc)$ = Average temperature difference between evaporator and condenser in ºC

Rth =Thermal resistance ºC/W

The higher heat transfer rates of system occur with lower resistance values. The resistance to heat transfer is given by thermal resistance.

The values of thermal resistance are plotted against heat input for different fill ratios and for different orientations for the fluid mixtures considered for experimentation. It is observed that thermal resistance is having lowest value at 50% fill ratio compared to 60% and 75% fill ratios at lower heat inputs. At this fill ratio the bubble formation is sufficient for heat to be transferred from one section to other of CLPHP. With higher heat inputs the performance is good at 60% fill ratio. It is observed that 75% fil ratio shows comparatively low performance with that of other fill ratios. At very low heat input i.e. at 20 W and on lower than that value, the CLPHP performance is very poor due to insufficient bubble formation. With increase of heat input to very high values also the performance goes worsen due to the presence of more quantity of liquid is present in the tube. At higher heat inputs the tube is fully filled with bubbles hence formation of new bubbles will be very less. This leads to poor performance. By taking Rth on y-axis and heat input on x-axis the following graphs are drawn for ethanol-acetone mixture.

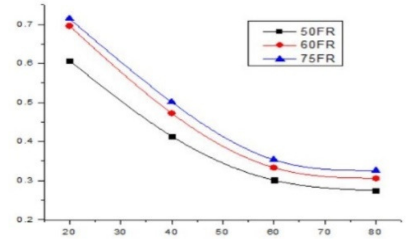


Fig. 3. Variation of thermal resistance with heat input for Ethanol-Acetone mixture.

For different fill ratios (50%, 60% and 75% fll ratio): From the graphs the variation of heat input is from 20W to 80 W for Ethanol-Acetone mixture. In this case thermal resistance value is very high at 20W compared to other heat inputs due to insufficient bubble formation at low input heat values.

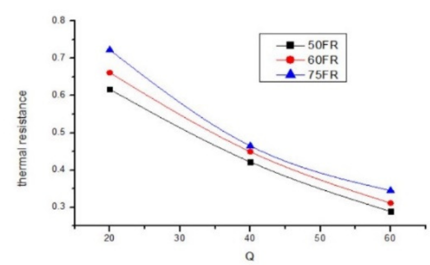


Fig. 4. Variation of thermal resistance with heat input for Ethanol-Methanol mixture for different fill ratios (50%, 60% and 75% fll ratio).

For Ethanol-methanol mixture variation of thermal resistance is observed from a heat input of 20W to 60 W only. At 60 W after reaching steady state the evaporator tubes 15, 16, 19, 21, 25, 27, 28 numbers are becomes dry. That means dry-out condition is observed at 60 W in evaporator tubes. For Ethanol-Water mixture the experiment is carried out from 20-100W of heat input values as shown in the graph. At 60 w almost at all the fill ratios the thermal resistance shows very small difference. As the heat input increases further the curve deviates from 50 fill ratio to 75 fill ratio.

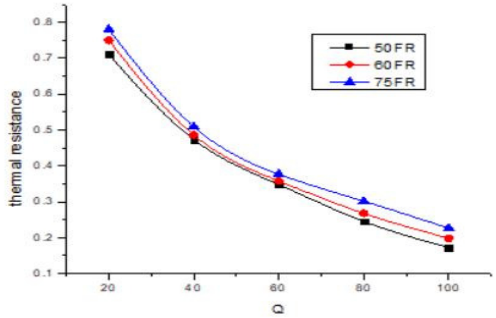
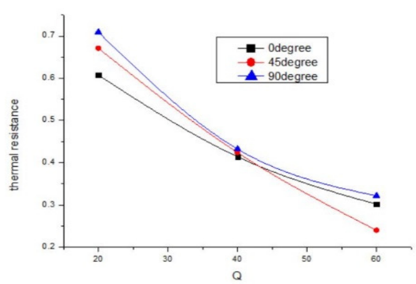


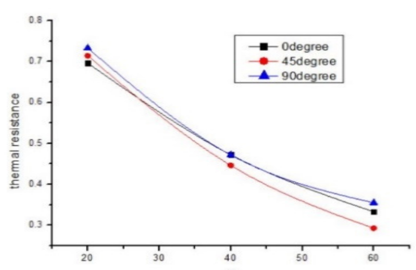
Fig. 5. Variation of thermal resistance with heat input for Ethanol-Water mixture for different fill ratios (50%, 60% and 75% fll ratio).

Among all the mixtures Ethanol with Water, Methanol and Acetone at 20 W Ethanol with acetone shows least thermal resistance and its value is 0.60734 ºC/W.

Inclination Effect on CLPHP: The orientation of tubes strongly influences the performance of CLPHP. For orientations of 180 –degree and 135-degree positions observable pulsations are not observed. At this orientation the evaporator temperature increases sharply results the difference in temperature between evaporator and condenser is almost negligible. Therefore the experimentations are carried out for inclination orientations of 0º, 45º and 90º. The thermal resistance decreases with increase in heat input results the pulsating behaviour of tubes. Compared to 0-degree, at 45-degree higher resistances are observed upon supplying equal input heat. Further increasing inclination angle the buoyancy force decreases and the formation of bubbles to the surface of liquid increases. And also in the performance analysis pressure difference is very important which is due to higher amounts of heat input. The following curves show the heat input and thermal resistance variation for working fluid mixtures considered for experimentation.



(a)



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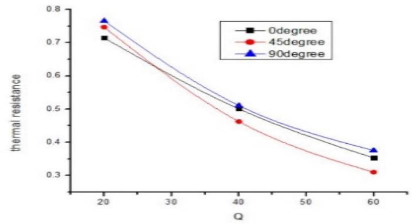
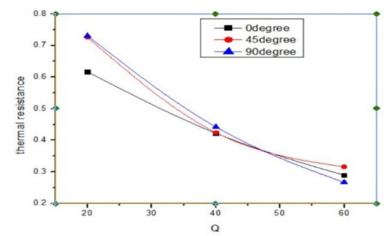


(c)

Fig. 6. Variation of Thermal resistance with heat input at different inclinations at (a) 50% fill ratio (b) 60% fill ratio and (c) 75% fill ratio for Ethanol-Acetone mixture.



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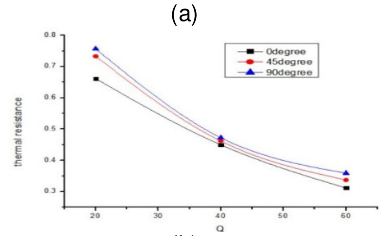

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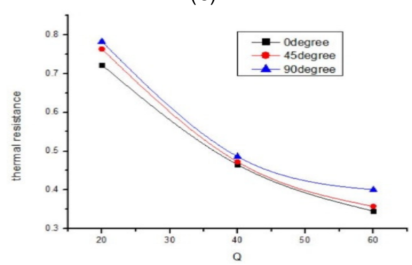
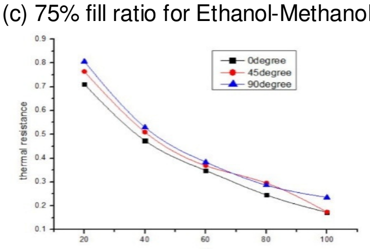
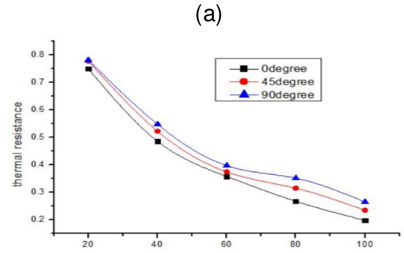


(c)

Fig. 7. Variation of Thermal resistance with heat input at different inclinations at (a) 50% fill ratio (b) 60% fill ratio and (c) 75% fill ratio for Ethanol-Methanol mixture.



(a)



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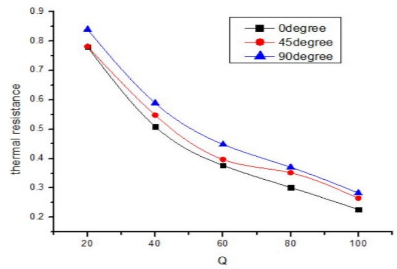

(c)

Fig. 8. Variation of Thermal resistance with heat input at different inclinations at (a) 50% fill ratio (b) 60% fill ratio and (c) 75% fill ratio for Ethanol-Water mixture.

The thermal resistance variation with varying heat input value stepwise is shown in the graphs for Ethanol-Acetone, Ethanol-Methanol and Ethanol-Water mixtures. For Ethanol-Acetone mixture at 50 % fill ratio pulsations are observed at all tubes for 0 and 45-degree orientations but dry out is observed at evaporator tube number 23 for 90-degree inclination orientation. For Ethanol-Water mixture vertical bottom heating that is 0-degree position shows very less thermal resistance value as the difference in temperature between evaporator and condenser is high. This is due to gravity which helps liquid slugs to flow back from condenser section to evaporator section. Maximum thermal resistance is given by 90-degree orientation position and 45-degree inclined position gives performance in between 0 –degree and 90-degree positions.

Among all the fluid mixtures Ethanol-Acetone at 0-degree inclination and 50% fill ratio shows better performance.

Effect of Heat Input: When fluid is not filled inside the PHP, the heat transfer from evaporator section to condenser section is essentially by pure conduction. When a working fluid is filled completely in a PHP, i.e., when the fill ratio is 100%, the transfer of heat is mainly due to buoyancy induced liquid circulation in PHP. But if a fluid is partially filled in the PHP, the fluid forms liquid slugs and plugs. Under such initial conditions, if the heat is applied at the evaporator, difference in pressures is created between both the sections, which causes the flow of vapour from evaporator to condenser and gravity assisted return of liquid takes place. This results in a self-sustained pulsating action of fluid inside the PHP. However, the minimum heat flux required for initiating the pulsating action depends on the Woking fluid. Accordingly, for each working fluid, the minimum heat flux needed for initiation of pulsating action is noted at the same is presented in Table 2 for all the working fluids considered in the analysis.

During experimentation at evaporator section heat input was supplied by variac. Heat input was increased step wise and then the thermocouple readings are recorded once the system reaches steady state. The procedure repeated until rapid increase in evaporator temperature starts. Once the dry out is reached means performance limit for heat input is reached. For acetone at lower heat inputs the bubbles formation is very slow. It takes more time to reach fluid from evaporator to condenser. Therefore the temperature rise of the cooling fluid is very less. This results condenser temperature values in lower value.

Experimental investigations shows that for Ethanol-Acetone it took 8 min to initiate pulsation at 20W. For Ethanol –Water at 20 W considerable pulsation was not observed immediately, minimum of 20 min was taken for initiation of pulsation. For Ethanol-methanol liquid slugs and vapour plugs are observed after 10 min of initiation of heat supply.

Table 2: Operating conditions of working fluids.

Working fluid	Saturation temp. (ºC)	Heat input applied (W)	Time taken to initiate pulsation(min)
Ethanol-Methanol	78.23	20, 40, 60	10 min
Ethanol-Water	64.7	20, 40, 60, 80, 100	20 min
Ethanol-Acetone	56.25	20, 40, 60, 80	8 min

At initial states for lower power input values there is no considerable pulsation is observed. They are not capable of generating enough liquid slugs and vapour bubbles for heat transfer. This results poor performance of PHP. As the heat input is increasing step wise up to certain value, the flow takes place in fixed direction. At this point there is no reversal flow occurs with respect to time. Due to circulation of fluid the tubes alternately becomes hot and cold. This results as change in evaporator and condenser temperature difference of tube. The experimental tests are repeated until it reaches to stable condition. By increasing heat input thermal resistance decreases for all the working fluids. The time taken for pulsation is very less as the angle of inclination increases for the same fill ratio.

VII. CONCLUSIONS

– At 50% fill ratio, pulsations are not observed for lower heat inputs i.e. less than 20 watt.

– Closed loop pulsating heat pipe can functions successfully at an inclinations angle from 0-degree to 90-degree orientations. Whereas the operation fails at 135-degree and 180-degree positions.

– Dry out can be observed in evaporator tubes once the fluid reached higher temperature than its boiling point value of the mixture.

– Gradual reduction in thermal resistance values were observed upon increasing heat input in all the mixtures considered.

–Gravity effect plays important role on performance of CLPHP of Ethanol with acetone mixture compared to other mixtures. Ethanol with Water shows negligible gravity effect whereas Ethanol with methanol shows considerable effect.

– Vertical bottom heating i.e. 0-degree orientation gives better performance than other orientations.

– The performance of CLPHP is more effective due to the orientation of tubes. Rapid decrease of thermal résistance occurs at lower heat input values with respect to inclination effect and smooth decrease occurs as the hat input keep on increasing.

– Under stable operating conditions higher heat performance of CLPHP can be obtained at lower filling ratio.

– Ethanol when added to Acetone there is considerable improvement in heat transfer is obtained compared to Ethanol added to Methanol. Therefore Ethanol- Acetone is preferred compared to Ethanol- Methanol. Ethanol-acetone shows least thermal resistance and its value is 0.60734 C/W.

– Among all the fluid mixtures Ethanol-Acetone at 0-degree inclination shows better performance.

– In vertical position thermal performance is improved compared to horizontal position. Due to presence of gravity vertical position is always sows better performance.

VIII. FUTURE SCOPE

The experiments can be conducted by considering mixtures of different proportions.

Nanofluids can also be implemented as working fluids.

Conflict of interest. No conflict of interest.

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