Effect of Design Parameters Investigation on Thermal Performance of A Pulsating Heat Pipe

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Abstract- This paper briefly Experimental Investigation conduct on a closed loop Pulsating heat pipe for asses the heat transfer performance. The PHP has a eight loop made of Copper pipe. Working fluids using DI Water fluid different filling ratios in 45%,55%,65%,75%, and 85%. The heat input is varied between 120W-600W in steps size of 120W. All experiments are conducted in the bottom heating mode in vertical. The parameters considered for evaluating the thermal performance are the temperature difference between evaporator and condenser, thermal resistance, heat transfer coefficient. The results of the investigation reveals that, the vertical orientation and increase in filling ratio better heat transfer performance. most effective design parameters considered heat Input, number of turns, working fluids, pre-installation conceptual model, working with type heat pipe, suitable Materials selection, Filling ratio, Role of gravity, Orientation of PHP, aspects ratio, diameter these start up characteristics, the thermal resistance decreases rapidly with the increase in the heating input and it is observed that lower value of thermal resistance is obtained at a filling ratio of 55%. Hence DI Water exhibits better performance at a filling ratio of 55%.

Keywords – Parameters of PHP, Filling Ratio, Heat Input, Pulsating Heat Pipes

I. INTRODUCTION

A closed loop PHP is a meandering, capillary tube that is closed ends are connected, Evacuated and partially filled with a working fluid, resulting in an alternation of vapour bubbles and liquid slugs. It was patented in its most popular version by Akachi [2] [3] in the early 1990s .Even though many distinct flow pathways have been seen during PHP's operation (e.g. anular, semianular, stratified) [4], the most prevalent is restricted slug flow. The device's performance and functioning are largely dependent on the system's ability to maintain non equilibrium circumstances [5]. [6], implying that a PHP can only be defined in terms of the local distinct thermodynamic states connected with it.The device's performance and function are largely dependent on the system's ability to maintain noneuilibrium circumstances [5] [6], which implies that a PHP can only be characterised in terms of localised thermodynamic states associated with various physical zones. Authors give an overview on pulsating heat pipes. PHPs have immerged as an interesting alternatives to conventional heat transfer devices. A closed loop pulsating heat pipe is better than open loop pulsating heat pipe because of possibility of fluid circulation. The CLPHPs are the devices which lie between conventional Heat pipes and extended surfaces metallic fins for heat transfer. Internal tube diameter, input heat flux and the filling ratio are the basic boundary conditions which are to be satisfied for the structure to work as a pulsating heat pipe[23].

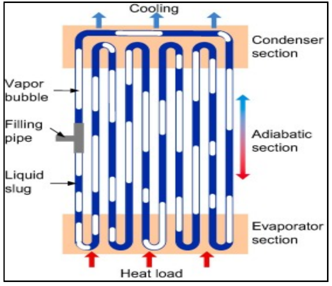

Figure 1.Closed Loop Pulsating Heat Pipe

This system incorporates FC-72, ethanol, and demonized water as the working fluids. The experimentally determined optimal fill ratio is suggested to be70% for the three working fluids. Lower fill ratios such as 60% and higher fill ratios such as 80%.result in worse thermal performance of the looped PHP for all three working fluids. The looped PHP with water as working fluid provides the best overall thermal performance.An experimental study is performed to compare the performance of a Flat Plate Pulsating Heat Pipe(FPPHP) and a Capillary Tube Pulsating Heat Pipe(CTPHP). These two are compared on the base of flow regimes and the corresponding thermal performances at varying heat inputs (20W to 180W) with filling ratios of 40%, 60% and 80%.Ethanol is used as a working fluid. It is observed that amplitude of oscillations in higher in CTPHP than FPPHP. The thermal resistance is reduced by 83% and 35% in FPPHP and CTPHP respectively in presence of working fluid. An experimental work is performed with three dimensional closed-loop pulsating heat pipe charged with DI water and surfactant(hex adecyltrimethyl ammonium). Input heat load (10W, 20W, 30W, 40W) and initial pressure (0.1MPa, 0.07MPa, 0.05MPa) is varied to compare characteristics. CLPHP with surfactant works better at low initial pressure. The thermal resistance is decreases by 4.78% with initial pressure, the heat input load and the surfactant concentration is 0.05MPa, 40W and 50ppm respectively compared with CLPHP with DI water. Surfactant also improves the wet ability of the CLPHP wall, reduce the contact angle and completely prevent the “dry-out” condition

II. SIGNIFICANT DESIGN PARAMETERS FOR PHP PERFORMANCE

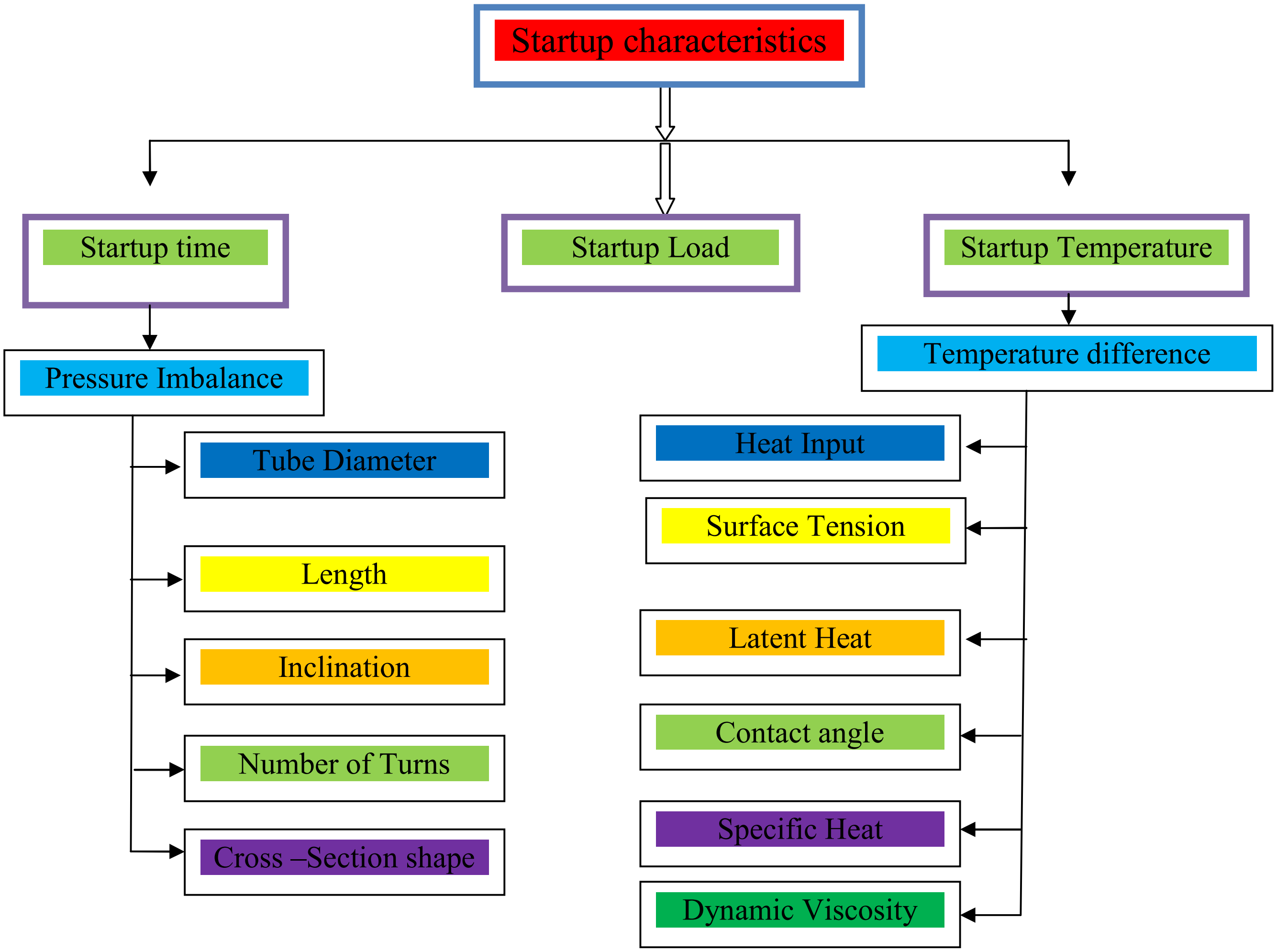

Figure .2.1Influences of different parameters on start-up characteristics of PHP

2.1 Heat Input

The device will not function as PHP if the heat input to the evaporator is less than the startup heat input. By storing heat in the fluid, it functions as insulation. Part of the total heat input given to the evaporator section is transformed into kinetic energy of the working fluid in order to maintain pulsations and push the fluid from the evaporator to the condenser. Increased heat input improves PHP performance by enhancing pulsation motion. Heat input of up to 200 watts is evaluated. The applied hotness transition influences the accompanying, Internal bubble elements, sizes and agglomeration/breaking examples of stream qualities. Level of bothers and stream hazards during stream. Flow design progress from hair like slug stream to semi-annular and ring-formed lastly to annular stream. Since the Info heat gives the siphon power, under an exact level, no motions start, for good measure of CLPHPs, a simplex current stream still up in the air at high hotness transitions. Furthermore, the stream conjointly gets revised from periodical slug stream to ring-molded stream. When a stream not really set in stone, rotating tubes areas become hot and cold (hot liquid streams from vanishing one cylinder and cold liquid from the condenser streams inside the adjoining tube).

2.2 Numbers of Turns

Heat Flux should be fed into the apparatus. The applied hotness transition influences the accompanying: Internal bubble elements, sizes and agglomeration/breaking examples of stream qualities. Level of liquid and vapor creating during stream. Flow design progress from hair like slug stream to semi-annular and ring-formed lastly to annular stream. Since the Info heat gives the siphon power, under an exact level, no motions start, for good measure of CLPHPs, a simplex current stream still up in the air at high hotness transitions. Furthermore, the stream conjointly gets revised from periodical slug stream to ring-molded stream. When a stream not really set in materials, rotating tubes areas become hot and cold (hot liquid streams from evaporation one cylinder and cold liquid from the condenser streams inside the adjoining tube).

2.3 Working Fluid

an oscillating or pulsating heat pipe (PHP) has been discovered to be one of the most effective cooling systems. The experimental tests are carried by working fluid more significantly working.

Table 1: Properties of working fluids

Working Fluids	**Boiling Point in**	**Melting Point (for Solid State)**	**Useful Temperature**	**Specific Heat Cp(J/kg-K)**
Acetone	**57**	**-95**	**0.-120**	**2031**
Methanol	**64**	**-98**	**10-120**	**2470**
Ethanol	**78**	**-112**	**0-130**	**2470**
Benzene	**80.10**	**5.5**	**0-140**	**1968**
DI-Water	**99.98**	**0**	**30-170**	**4190**
Ethylene Glycol	**187.4**	**-12.9**	**-12.9-250**	**2360**

2.4 Pre-Installation Conceptual model.

Preinstallation refers to the requirements, supported configurations, and reserved or prohibited items that must be taken into account prior to installing a Pulsating Heat Pipe. Designing the evaporator and condensation sections, as well as analyzing the development of vapour plugs and liquid slugs, are the most fundamental requirements.A PHP is a simple meandering tube with multiple Uturns of capillary size. There is no extra capillary structure inside the tube, unlike a traditional heat pipe. The tube can be arranged in two ways: open loop and closed loop.

2.5 Working with Variable Selections

Open Loop: Tube ends are not linked to one another; instead, one long tube is bent in numerous turns and both ends are sealed when the working fluid is filled.The tube is connected ends in a closed loop. The tube is initially evacuated, then partially filled with a working fluid, which spontaneously distributes itself inside the capillary tube as liquidvapour plugs and slugs. A pulsing motion of the liquidvapour/bubbleslug system transfers heat from one end of this tube bundle to the other. In the middle, there may be an optionaladiabatic zone. To improve performance, one or more flowdirection control check valves may be installed at appropriate places.

2.6 Materials are chosen.

The materials utilised to create a Pulsating Heat Pipe have a significant impact on its thermal performance and operational life. When the working fluid and the materials within the PHP are incompatible, gas might form. This may be prevented by using materials that are compatible. For example, stainless steel and water normally produce hydrogen gas; however, if the stainless steel is passivated, no gas is produced, making it compatible.Aluminium and water are another frequent combination that creates hydrogen gas. Throughout the temperature range, the materials in contact with the working fluid should be chemically compatible. The requirements for material selection for a Pulsating Hea Pipe are identical to those for a traditional heat pipe or heat exchanger. Copper is used to make PHPs because of itse excellent heat conductivity and chemical compatibility with common working fluids.

2.7 Filling Ratio.

The filling proportion is the extent of a hotness line's volume that is first loaded up with fluid. At the point when the greatest hotness move rate is reached at the predetermined temperature, the ideal filling proportion is set up tentatively. Obviously, there isn't sufficient working liquid in the framework underneath FR 10% to consider huge reasonable and inactive hotness transmission. The evaporator tends to dry out the climate. With a high warm obstruction and a low heat Transfer limit, the hotness move execution is poor. Since there aren't sufficient air pockets to create siphoning activity more than FR 80%, Warm execution endures essentially. The PHP capacities are in a genuine beating state between generally 40% and 80% filling proportion, and the hotness obstruction is observably lower than in a 100% filled condition. In any case, the filling proportion raises the hotness transmission limit. Additionally, when the hotness input increments from lower to higher, the warm opposition varies less and less. The more grounded the hotness obstruction, the 45% to 85% of PHP. In the preliminaries, the ideal filling proportion for the PHP is around 55%, which best consolidates the advantages of the accompanying two perspectives: idle hotness joined with the siphoning activity of the air pockets, and reasonable hotness transmission of the fluid slugs.The effect of the pulsing heat pipe's orientation.

2.8 Role of Gravity

In the current analyses agreeable self-wavering activity of the gadget was just conceivable till a slant point of around 90◦ (warmer down position). All motions halted at flat direction. Greatest motions are acquired at vertical position.

2.9 Horizontal Orientation

In the flat direction, the gadget is kept in an even situation with the evaporator condenser segments at a similar level and there is no impact of gravity, there are no ceaseless temperature throbs and the evaporator temperature continues to increment. It very well may be reasoned that the CLPHP fizzles at this stage. It very well may be noticed that the enormous additions of the evaporator temperature with expanding heat flux and unsound temperature throbs are an indication of inadequate oscillatory flow in the device.

2.10 Vertical position

Since the CLPHP is in the upward direction, the working fluid gets back to the evaporator area and can move effectively in the gadget because of gravity impact. The working fluid in the even direction, gravity doesn't uphold the fluid development inside the gadget, and the hotness power without the help of gravity is a significant main thrust in fluid developments in this direction. Consequently, the gadget execution is sub-par in the even direction than in the upward direction. Along these lines, at wonderful vertical position the exhibition is ideal.

2.11 Aspect ratio

When the aspect ratios increase, the maximum heat flux decreases for all inclination angle. It can be found that the highest ratio of heat flux average to maximum heat flux average at 90° occurs at aspect ratio.

2.12 Diameter

The pressure driven width of the hair like cylinder decides the improvement of a fluid fitting and a fume bubble train inside PHP. PHP's pressure driven measurement Bond number (Bo) was utilized to settle on the choice. shows the gravitational power's harmony with the surface power of pressure The presence of Bo_2 (Dcritical) guarantees the in PHP, the production of a fluid slug and attachment train The area was overwhelmed by the surface strain power. Expanding Internal breadths not exactly $D_{Critical}$ give higher flow able cross-sectional region. Fume has a similar mass motion as gas. The speed is diminished, keeping it beneath the basic level. The speed at which the stream changes into annular stream. Besides, expanding the inside measurement has an effect.

2.13 The number of turns that should be taken at the most is called the optimal number of turns.

The warm presentation of the gadget firmly relies upon the quantity of turns, directions, and hotness flux, which thusly influence the inner fluid throbs. Viable warm conductivity is exceptionally alluring for some, heat move applications gadget. If by some stroke of good luck one copper tube is utilized, the radiator will go to some consistent state temperature. As the quantity of copper pipes is expanded, the net radiator power is fixed, the last consistent state temperature of the warmer will descend. Net hotness took care of per Copper line will diminish thus the general framework warm opposition, continues to diminish as the quantity of copper pipes increases.If the quantity of turns of the CLPHP is little, then, at that point, the hotness dealt with by each turn will be very high. Clearly since there isn't sufficient liquid stock and compelling warm cross-sectional region accessible for heat move, the general warm opposition will be high.If the quantity of turns of the CLPHP is expanded, the net hotness took care of by each CLPHP become lessens, the general warm obstruction should come down.It can be presumed that the mix of the quantity of turns and the hotness flux majorly affects the temperature throbs, which thusly influence the flow conduct inside the device.

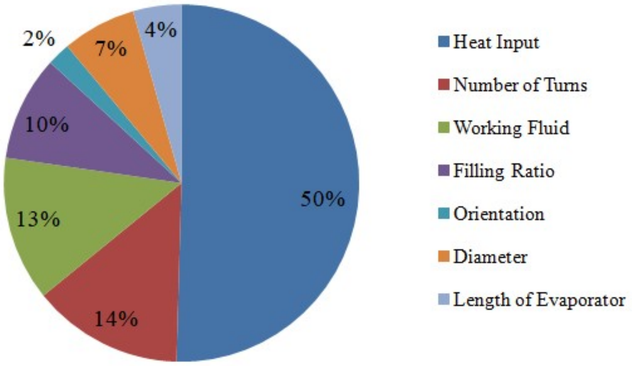

Figure.3.Contribution of an Individual Parameters

III. DIMENSIONLESS NUMBERS AND ITS SIGNIFICANCE

3.1 Kutateladze number (Ku).

The Functioning liquid utilized in shut circle throbbing hotness pipe has unique "basic hotness transition", The most noteworthy warm exhibition that hotness line can move before dry-out of fluid working liquid inside the evaporator segment will happen, Examination in warm execution of each functioning liquid through the hotness motion isn't sensible. The functioning liquid with moderately low basic hotness transition by and large has lower moved hotness motion than the higher one. To standardize the test information, Kutateladze number (Ku) was picked to be a delegate of the warm exhibition.

$$K_u = \frac{q_c}{\rho_v h_{fg}\left[\sigma g\left(\frac{\rho_l - \rho_v}{\rho_v^2}\right)\right] 1/4} \quad (1)$$

3.2 Bond Number (Bo)

Bond number is the dimensionless number engaged with working liquid properties and calculation of the hotness pipe. It is inferred to the proportion between lightness power and the surface strain power of the functioning liquid.

$$B_o = \frac{g(\rho_l - \rho_v)}{\sigma_s} \times D_i^2 \quad (2)$$

It was found from the study that when bond number increases the thermal performance decreases.

3.3 Prandtl Number (Prl)

Prandtl number is the dimensionless number engaged with the functioning liquid properties. It is inferred to the proportion between the kinematic thickness to the warm dissemination of the functioning liquid. Prandtl number include two stage Prandtl number of fluids working liquid and Prandtl number of fumes working liquid. Prandtl number of vapours working fluid rarely had an effect on thermal performance and hence could be neglected.

$$P_{rl} = \frac{\mu_l C_{pl}}{K_l} \quad (3)$$

3.4 *Jacob Number (Ja)*

Jacob number is the dimensionless number associated with working liquid properties. It is suggesting to be the proportion of hotness amount that a hotness line can move between two distinct instrument idle hotness and reasonable hotness. At the point when the Jacob number builds the warm presentation increments if there should be an occurrence of shut circle throbbing.

$$J_a = \frac{h_{fg}}{C_{pl}(\Delta T)_{sat}^{e-c}} \quad (4)$$

3.5 *Karman Number (Ka)*

Karman number is the dimensionless number involved with working fluid properties and geometry of the heat pipe which is similar to B_o. It represents a ratio between driving force and frictional force of working fluid.

$$K_a = \frac{\rho_l \times (\Delta P)_{sat}^{e-c} \times D_i^3}{\mu_l^2 \times L_{eff}} \quad (5)$$

IV. EXPERIMENTAL SETUP AND PROCEDURE

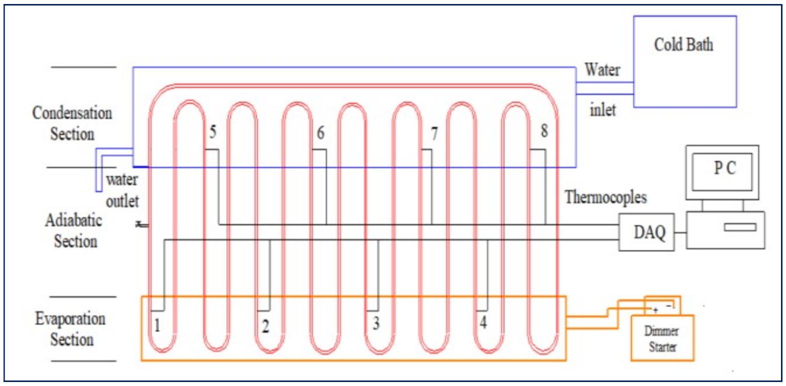

Figure .2. Schematic diagram of the Experimental setup.

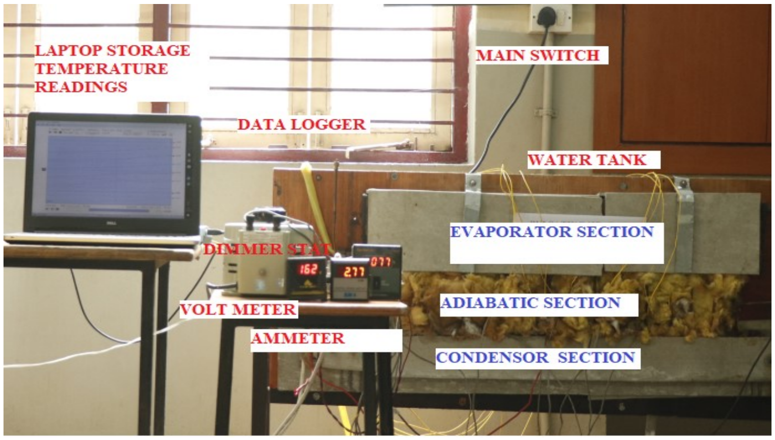

Figure.4 Experimental setup of PHP

Figure 4. shows the scheme diagram for the eight PHP test configurations. The average PHP length measures 80cm and 7.5cm width. The capillary tubes are calm in copper and have an inner diameter of 2mm and an outer diameter of 3mm. Copper is used as a cylinder material because it is a heat transfer agent. PHP operates at a reliable temperature rise (up to 400 ° C) Using a Mica strip temperature measuring 7.5cm x 80cm restrain 0-1000W used to heat part of the evaporator. The line radiator is connected to a power source using a power supply (autotransformer) holding 0-230V / 10A. The autotransformer helps to bring the right voltage into the radiator. The radiator is kept everywhere using glass wool to protect it from any heat waves. The condenser part is the radiator exchanger where the copper tube contacts the operating . The regular water supply is guaranteed by using a head tank used for this purpose placed on a high surface. Flexible tubes bring water from the tank to the condenser. Temperatures are measured in a few places on the evaporator and parts of the condenser using six T-type thermocouples. Thermocouples are attached to tubes of copper. The analog temperature data obtained from thermocouples is entered / stored on a desktop computer after converting it to a digital website using a 12-channel statistical logger (Make: Measurement Computing). The entire test set is centered on a kindly wooden tilt board for any desired inclination.

Experimental Procedure

During the Experimental research , the following technique was followed

1. The PHP is totally drained of any liquid before the experiment begins by blowing air through it using a syringe.
2. The needed volume of working fluid (equivalent to a 55%filling ratio) was added through a syringe and the valve was then close
3. The controlled power supply unit is used to establish the heater's needed wattage. The trials in this study were carried out by adjusting the heat inputs from 120 W to 600 W in 120 W increments.
4. The flow of cooling water via the condenser portion was regulated to provide optimal cooling.
5. Temperature data recorder is turned on to record temperature values when stable state temperatures are reached. The frequency of data entry is set at 1 Hz (single temperature recorded per second).
6. Each test lasts about 60 minutes, with the constant temperature setting and the pressure constant in atmospheric conditions.
7. PHP tubes are reassembled after each route has been completed to replace the active fluid. Heat resistance as a heat input function (Qin) (Rth)

V. RESULTS AND DISCUSSIONS

5.1 Thermal Resistance(R_{th}) As a Function of Heat Input(Q_{in})

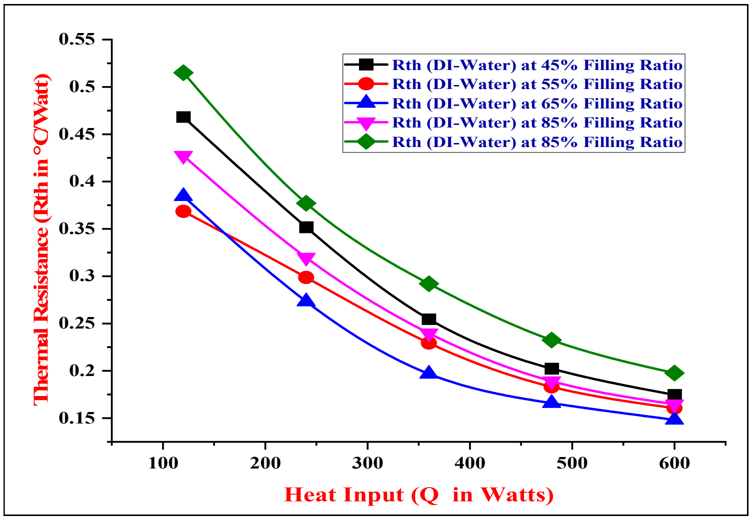

Figure 7. Thermal Resistance versus Heat Input

Figure.7 shows deviation of thermal resistance verses heat input intended for dissimilar filling ratios of 45%, 55%, 65%,75%,85%. it is pragmatic that thermal resistance declines very high during initial heat input due to low pulsations and gradually thermal resistance values reductions with increase in heat input because high pulsating movement. Distilled Water starts the pulsations in the intermediate temperature range 0^{0C} to 100^{0C}. It is found that form the results that at 55% substantial ratio lower assessment of thermal resistance of 0.153^{0}C/W is found at 600watts. Therefore the PHP functions well at 55% substantial ratio compared to other substantial ratios.

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5.2 Heat Input (Qin) has an effect on the Heat Transfer Co-efficient (h)

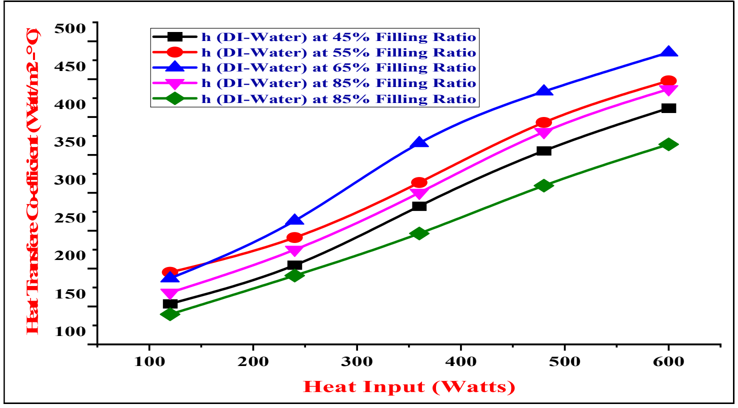

Figure 8. Heat Transfer Co-efficient versus Heat input

The figure.7 indicates the variation of heat transfer coefficient for different fluids in the vertical orientation for extraordinary heat inputs. The style located from the graphs is that the heat switch coefficient will increase with warmth inputs from 120W to 600Wwith step size heat input 120W. Among all the fluids, the highest heat transfer coefficient obtained is nearing 475W/m^2-°C. This may additionally additionally be attributed to the enhancement in thermal properties such as thermal conductivity of the DI water. it can be found that the equal expand in style of the heat transfer coefficient for all the working fluids with upward push in heat input is evident. Among all the working fluids tested. This once more can also be correlated with the values of thermal resistance and temperature difference between evaporator and condenser.

VI .CONCLUSION

An experimental investigation was conducted to evaluate the thermal performance of a Eight loop CLPHP. The working fluids used were DI water. The heat inputs were varied between 120W and 600W and performance parameters such as thermal resistance, heat transfer coefficient. The following conclusions can be drawn from the study.

1.Better thermal performance was observed in the vertical orientation as compared to the horizontal orientation.
2. Lower thermal resistance values were observed for the 65% of filling ratio as compared to other filling ratios.
3. With the increase in the heat input the performance of the PHP improves
4. The heat transfer coefficient values are higher with the increase in heat input.

VII. NOMENCLATURE

Δt=Temperature difference between evaporator and condenser,°C or K
g=Gravitational acceleration
hfg=Latent heat J/kg
K=Thermal conductivity W/m-k
ρ=Density kg/m^3
C_p =Specific heat J/kg-k
V=Superficial velocity,m/s
Ja=Jakob number
Bo=Bond number
Pr =Prandtl number
Ku=Kutateladze number
h = Heat transfer co-efficient w/m^2-°C
As = surface area heat transfer in m^2
L =length of PHP in m
A_{CS} = area of cross area of pipe in m
PHP =Pulsating heat pipe
T4,T3,T2,T1=Evaporator Temperatures in °C
T8,T7,T6,T5=Condenser Temperature in °C
Dcr = diameter of pipe in mm
g =acceleration due to gravity in m2/sec
DAQ = Data Acquisition System
FR = substantial ratio
M =merit number

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