ANALYSIS OF FLUID PROPERTIES OF CLOSED LOOP PULSATING HEAT PIPE AT DIFFERENT HEAT INPUT AND ORIENTATION

[1]Muthu P, [2]Alwarsamy T,
[1]PG Scholar, [2] Professor,
[1,]Department of Mechanical Engineering
[1]Government College of Technology, Coimbatore, Tamilnadu, India.

Abstract: Pulsating heat pipe are passive heat transfer device where heat transfer is higher as compared to the common heat transfer devices such as metal fins and Heat pipe. The main reason for this is the two-phase phenomenon occurinside PHPs with the oscillatory motion of the bubbles. The flow in pipe is Multi –phase flow, vapor plugs and liquid slugs are created in PHP due to the capillary action. In this work, CFD analysis on a two turn CLPHP in ANSYS FLUENT 15.2 with overall size of device being 60mmx 173mm, diameter 2mm and distance between the tubes as 20mm.The tubes were made of copper, 50% of the volume filled with water (working fluid).This project mostly focus on thermal resistance analysis of CLPHP at various orientation such as vertical, inclined 45˚ and horizontal.

***Index Terms*–Pulsating heat pipe, Two phase Flow, Computational Fluid Dynamics (CFD).**

I. INTRODUCTION

Pulsating heat pipe is a serpentine channel of capillary size. It is evacuated and in part filled with working fluid. Formation of liquid slug and vapor plug are observed due to the domination of surface tension force. Their operation is based on the principle of fluctuation for the working fluid and a phase change occurr in a capillary tube. The tube diameter should be small enough such that liquid and vapor plugs exit. It has simple design, low cost, high thermal performance, and rapid response to high heat load.PHP has been used as various applications such as electronic cooling, nuclear reactor.

PHP also known as oscillating heat pipe, transfer the heat from its evaporator region to the condenser region. In condenser the heat is dissipated to the sink, which it does by the phase change occurrence of the working fluid being filled in with certain volume ratio. This device has an ability to transfer a huge amount of heat over its length with a small temperature drop.

II.LITERATURE REVIEW

Dong Soo Jang et al.,(2018)A pulsating heat pipe (PHP) is an excellent cooling device based on the phase change of a working fluid. The objective of this study is to investigate the thermal performance characteristics of a PHP at various nonuniform heating conditions. The thermal performance of the PHP is measured by varying the dimensionless heat difference from 0 to 0.3, heat input from 30 to 100 W, and filling ratio from 50% to 70%. As a result, the optimal filling ratios for the best PHP performance and reliability are determined to be 50%, 60%, and 70%, at the dimensionless heat differences of 0, 0.2, and 0.3, respectively.

J.Venkatasureshet.al.,(2016)CFD analysis for the PHP is tested with different working fluids binary mixtures like water-methanol and water-ethanol for 50% fill ratio viz., for different inner diameters of 2mm and 3mm. The temperature distribution across the heat pipe was measured. The performance parameters such as temperature difference between evaporator and condenser, thermal resistance evaluated. CFD results demonstrate the heat transfer characteristics observing the performance of PHP is a numerical approach.

Vipul M. Patel et al.,(2016) investigated the effect of heat input and orientation on performance of CLPHP by conduct experiment on a nine turn CLPHP.. The gravitational effect was investigated by placing the evaporator heater at different orientations such as horizontal (90º), vertical top (180º) and bottom (0º) as well as inclined top (135º) and bottom (45º). The conclusion stated that the CLPHP failed to operate at inclined top heater (135°) and vertical top heater (180°). While it effectively performed at vertical bottom heater, inclined bottom heater (45°) and even at horizontal orientation (90°).

Subhash Y. Nagwaseetal.,(2013)conducted experiments on a closed loop pulsating heat pipe (CLPHP) with 2mm diameter and in vertical position-bottom heating mode. Di-water was selected as working fluid for different heat loads to assess the thermal performance and the CFD simulation was also carried out to compare its experimental results.It was concluded that simulation with unsteady model was successful to reproduce the same behavior of vapor generation in evaporator and oscillation due to the pressure difference. It was proved that the heat transfer takes place due to oscillation of liquid and vapor.

Sameer Kandekaretal.,(2003)provided an overview on the definition of heat pipe which summarized that three thermo-mechanical boundary conditions i.e., internal diameter, input heat flux and filling ratio are to be satisfied for the structure to behave as a true pulsating device. It also stated the tubes have slug flow and annular flow and then the bulk flow takes the fluid direction.

Akachi et al.,(1990) Since the introduction of Pulsating Heat Pipes into the modern world where every aspect is in a verge of miniaturization, researchers have been showing a lot of interest in the development and up gradation of PHP. In this chapter some of the recent literature regarding the effect of orientation and heat flux has been discussed.

III.METHODOLOGY:

- To thoroughly perform literature survey on the effect of orientation and heat flux on PHP.
- To select the size and shape (dimensional parameters), working fluid, fill ratio based on the literature survey.
- To conduct, numerical analysis, modelling and meshing of geometry.
- To optimize the solution controls and solution algorithms to suit the given numerical analysis.
- To validate the numerical model with the available experimental data reported in the literature.
- To repeat the analysis for different heat inputs and orientations.

IV.MODELING AND ANALYSIS OF CLPHP IN CFD

Geometry

A overall size of the CLPHP is 60 mm x 173 mm, distance between tubes being 20 mm and the diameter as 2mm.Since in this present work focuses on the differet orientation of the CLPHP, the geometry is designed for all the three (Vertical, Horizontal, Inclined) cases saperately with same dimensions.

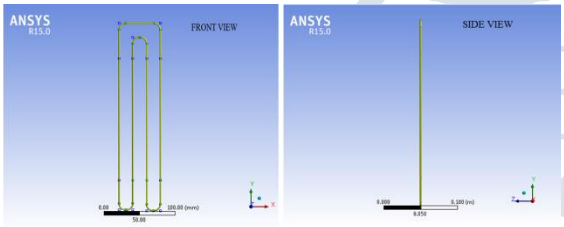

Fig 4.1-Vertical CLPHP geometry

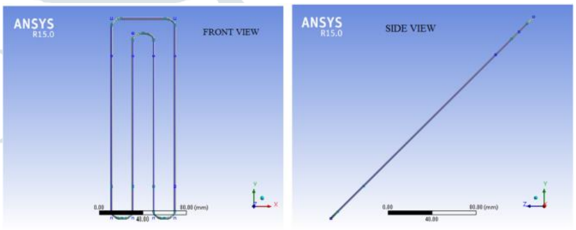

Fig 4.2-Inclined at 45° CLPHP geometry

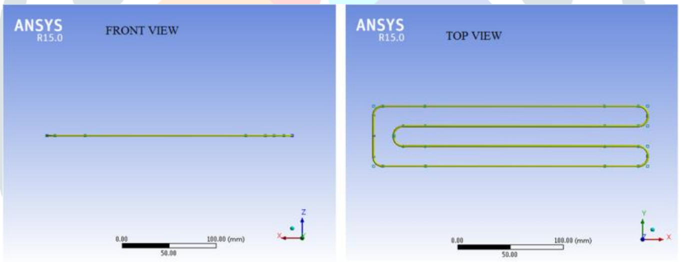

Fig. 4.3-Horizontal CLPHP geometry

Meshing

In order to analyze fluid flows, flow domains are split into smaller sub domains (made up of geometric primitives like hexahedra and tetrahedra in 3D and quadrilaterals and triangles in 2D.The sizing for the mesh is done manually.

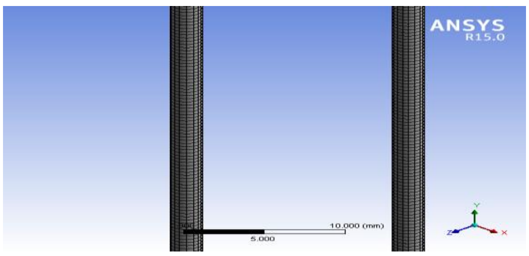

Fig. 4.4 Discretization of the geometry

Table 4.1 Number of elements and node

Position	Vertical	Inclined 45˚	Horizontal
No. of nodes	95,236	12,543	94,642
No. of elements	81,485	17,965	80,298

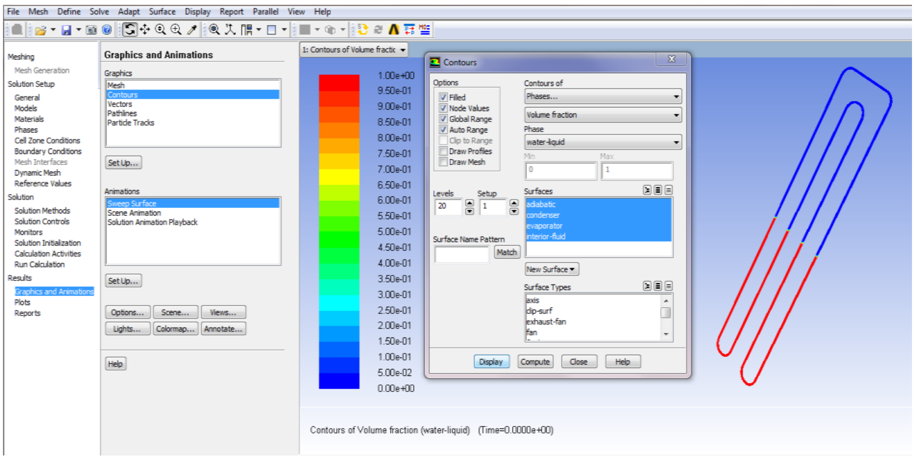

Fig. 4.5 checking the phase distribution

V.VALIDATION OF NUMERICAL VALUE AND COMPARE WITH THEORETICAL VALUE:

The Thermal Resistance of PHP is calculated by

$$R = \frac{T_e - T_c}{Q} \quad (K/W)$$

Where

Q= heat input in W

T_e= Average Evaporator Temperature in K

T_c= Average Condenser Temperature in K

The temperatures obtained for the evaporator and condenser section for vertical operating mode at 16W heat input have been listed below.

T_e=300.28 K, T_c=300 K

$Q = P - Q_{loss}$(Considering the thermal losses)

P = 16W

Q_{loss}= 1.6W (10% of heat loss [12])

Q = 16-1.6=14.4W

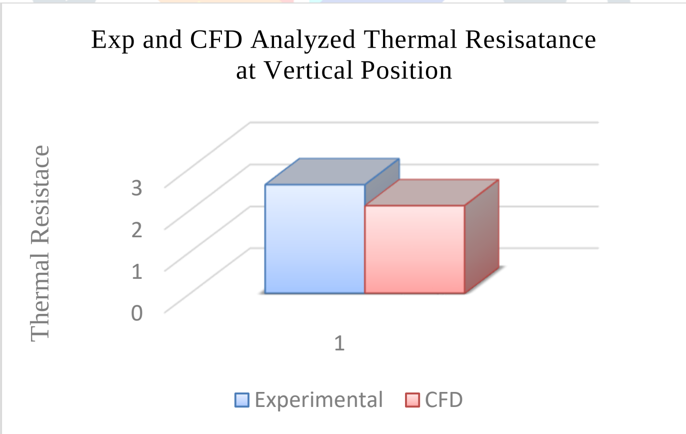

Fig. 5.1 Experimental and CFD analysed thermal resistance

$R = \frac{330.28-300}{14.4} = 2.1$ K/W

$\% \text{ Deviation} = \frac{R_{exp} - R}{R_{exp}} \times 100$

Experimental thermal resistance, R_{exp}=2.6 K/W

Numerical thermal resistance, R=2.1 K/W

$\% \text{ Deviation} = \frac{2.6-2.1}{2.6} \times 100 = 19.23$

The deviation calculated is 19.23%, which is within the numerical accuracy as shown in the Fig. 5.1 Thermal resistance is calculated for all the heat inputs viz. 16W, 32W, 48W using the eq. 5.1 and weighed against the experimental results by Pramod R. Pachghare

5.1 Thermal Resistance Of CLPHP Over Heat Input:

Thermal resistance is the most important parameter for optimal PHP performance and is a function of the temperature state conditions between the evaporator and condenser.

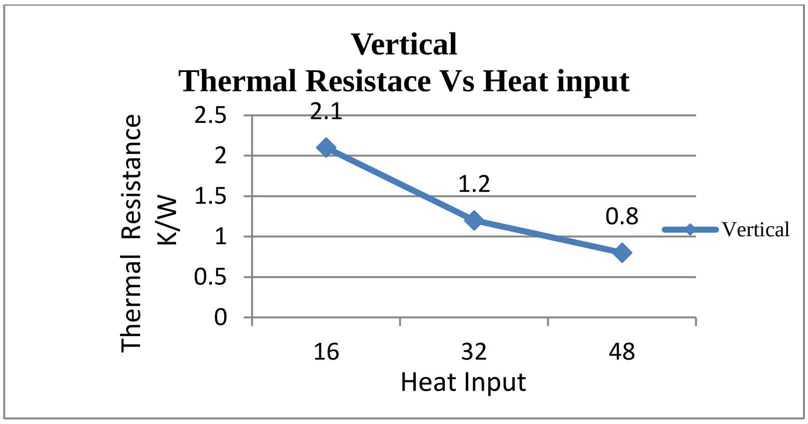

Fig. 5.2 Vertical- Thermal resistances (CFD) at different heat inputs

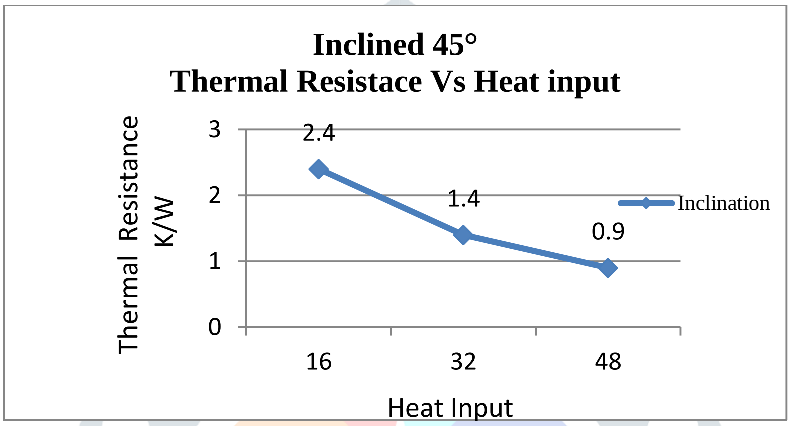

Fig. 5.3 Inclined 45º -Thermal resistances (CFD) at different heat inputs

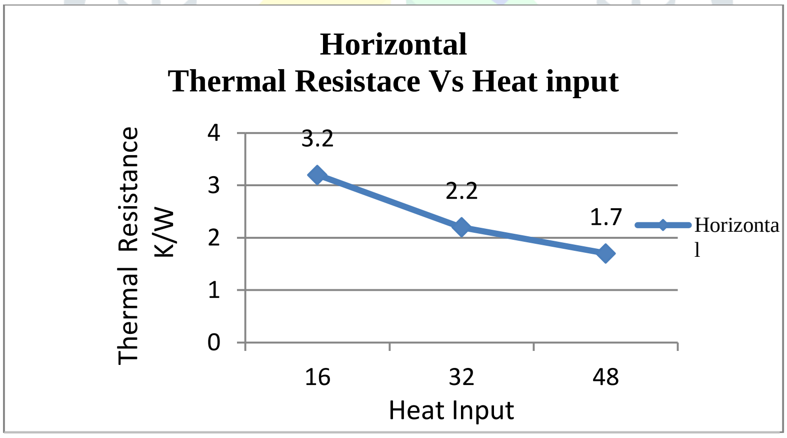

Fig. 5.4 Horizontal- Thermal resistances (CFD) at different heat inputs

For all orientations considered in the analysis, the thermal resistance is observed to decrease with the increase of heat input imposed at the evaporator as shown in Figs. 5.3 to 5.5

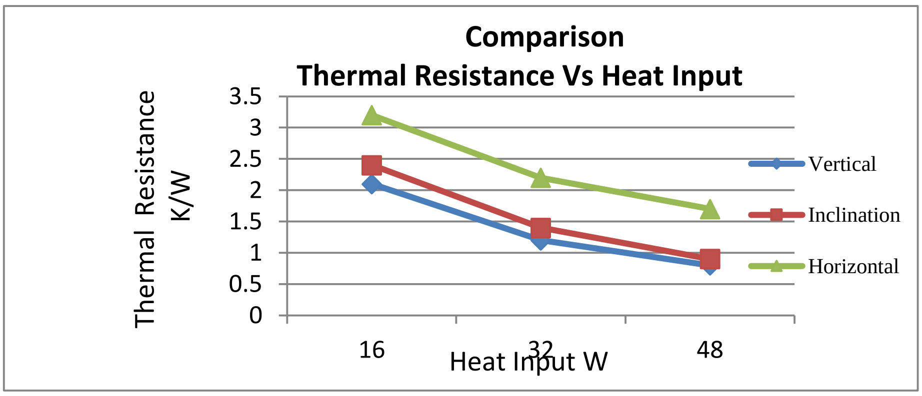

Fig 5.5 comparison of thermal resistance Vs Heat input

In inclined operating mode thermal resistance is high at 16W heat input and gradually decreases at 32W and 48W as shown in Fig. 5.6. The thermal resistance for horizontal case is very high at 16W heat input when compared to the other two cases. Thermal resistance in vertical case is considerably less when compared to other two operating modes.

VI. RESULT AND DISCUSSION

6.1 Illustrationof Pulsating Phenomena Through Graphs:

Four arbitrary planes have been selected in each section (condenser, adiabatic, evaporator) of the geometry for vertical position as shown in Fig. 6.1. Planes 1 to 4 sequentially represents locations in the four legs from left to right in each of condenser, adiabatic and evaporator sections. Variations in the pressure and velocity in those planes over time has been recorded at various heat inputs in order to get a clear insight of the pulsating phenomena in the CLPHP. The oscillations in the pressure and velocity curve illustrate the motion of the fluid within the tubes.

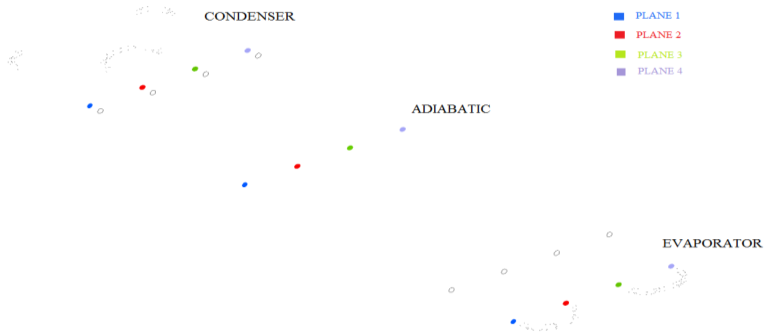

Fig. 6.1 Representing planes in each section

6.2VERTICAL ORIENTATION-VELOCITY VARIATIONS:

Condenser Section*:*

In the condenser section the velocity variation depicts the association and collapse of the vapour bubble imply the condensation phenomena in the section as shown in the Figs. 6.2 to 6.10

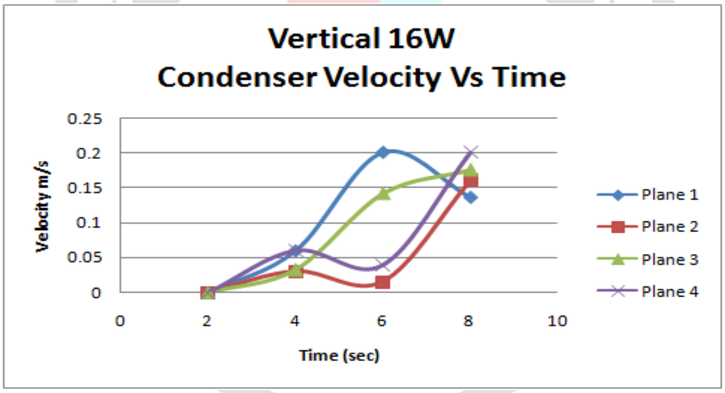

Fig. 6.2 Condenser: Variations in velocity of fluid in various planes over time at 16W

In the condenser section at 16W, increase in velocity of the fluid is observed in all the planes from 2sec owing to the disturbance in the evaporator section due to the triggering of the vapor bubble formation. finally at 4 sec in Planes 2, 4 and 6sec in Plane 1, the velocity is observed to reduce as shown in Fig. 6.2 depicting a collapse of the vapour bubble giving away the heat to the condenser section (Condensation phenomena). This condensed fluid flows back to the evaporator from the condenser through Plane 4 in outer leg of the pipe towards right as shown by the increase in velocity in Plane 4 at the end of 8 seconds as shown in Fig. 6.2.

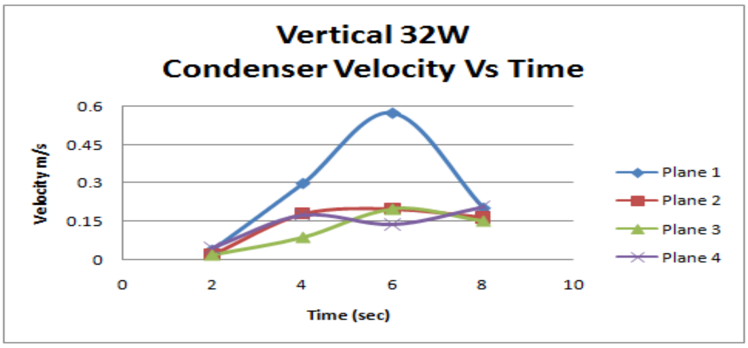

Fig. 6.3 Condenser: Variations in velocity of fluid in various planes over time at 32 W

At 32 W, the fluid motion in Plane 4 is observed to raise with higher velocities between the time interval of 4sec and 6sec as shown in Fig. 6.3 compared to the 16 W ,while the bubble train shoots up into the condenser section. The decrease in the velocity after 6 sec depict the disintegrate of the vapour bubble. This decrease in velocity is observed at 6sec in Plane 4 and at 8sec in Plane 3which indicates that the condensation has occurred in those planes. The increase in the velocity in Plane 4 from 6 sec onwards, depicts the fall of the condensed fluid (assisted by gravity).

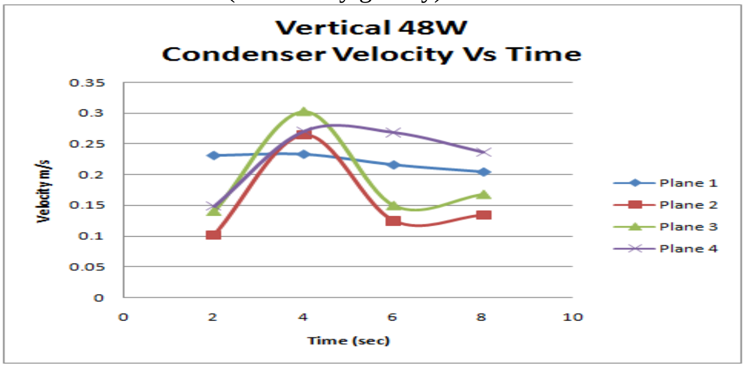

Fig. 6.4 Condenser: Variations in velocity of fluid in various planes over time at 48W

At 48W the velocity is observed to be high well before 2sec predominantly in Plane 1 as shown in Fig.6.4 as the evaporation process is faster compared to other two heat inputs. While in Planes 2 and 3 the velocities are experiential to be increasing at 4sec representing the movement of the hot fluid through condenser section and finally at 6sec the decrease indicate condensing process. The same is corroborate with the sudden decrease in pressure alongside these two planes in Fig. 6.4. Further increase in the velocities at 8 sec in Planes 2 and 3 indicates the fall of condensed liquid back to the evaporator. The reason that the condensed fluid takes longer time to fall reverse to the condenser at higher inputs as in this case is because of the local stopover causing reverse flow that show the way to thermal instabilities. The lack of the sudden decrease in velocity alongside Planes 1 and 4, show that the condensation has not yet happening along these planes and the increase in velocity in the other two planes also, suggest that complete onset of condensation will need further time.

Adiabatic Section*:*

The vapour bubble train moves up through the adiabatic section to the condenser section. This movement of the bubbles is studied through the velocity variations plotted over time as shown in Figs. 6.5 to 6.7 for different heat fluxes.

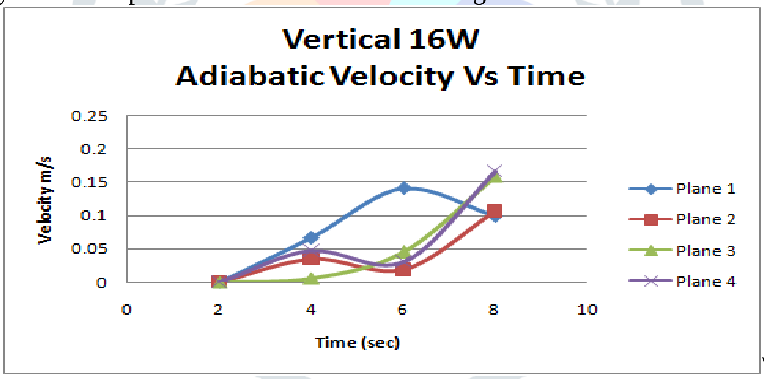

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Fig. 6.5 Adiabatic: Variations in velocity of fluid in various planes over time at 16W

In the adiabatic section at 16W heat input the increase in the velocities indicate the dislocation of the water-liquid is observed at 2sec through the Planes 1,2,4, whereas it took 4sec in Plane 3 as shown in Fig. 6.5.This dislocation is due to the evaporation in the evaporator section, which expands the water-liquid displacing it in the upward direction. As the time progress the water liquid in the CLPHP forms a train of vapour bubbles moving up from the evaporator to the condenser through the adiabatic section. These vapour bubbles disperse the heat in the condenser section lowering the velocity of the bubble train which more impacts the fluid movement in adiabatic section decreasing the velocities in Plane 2 and 4as shown in the Fig. 6.5. The increase in velocity at 8sec in Plane 4 depict the movement of the condensed fluid back to the evaporator.

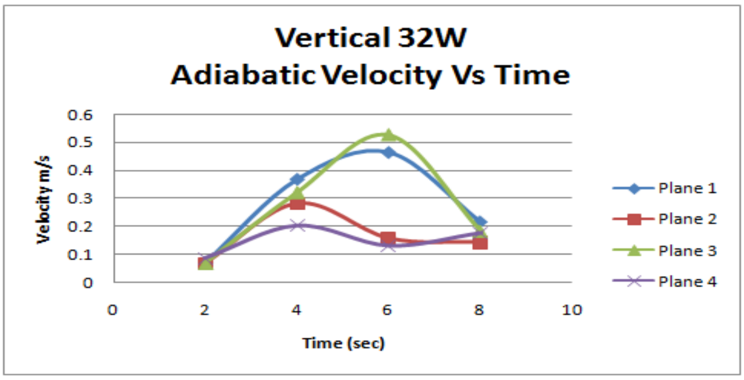

Fig. 6.6 Adiabatic: Variations in velocity of fluid in various planes over time at 32W

The same scenario holds good for the heat input of 32W and 48W except for the fact that at 32W in Plane 3, increase in velocity is observed from 2sec to 6sec at 32W and 2sec to 4 sec in 48W as shown in the Figs. 6.5 and 6.6 respectively. Velocity deviation is due to the condensation phenomena taking place in both tubes, the velocity of the upward moving vapour bubbles decreases in Planes 2 and 4.

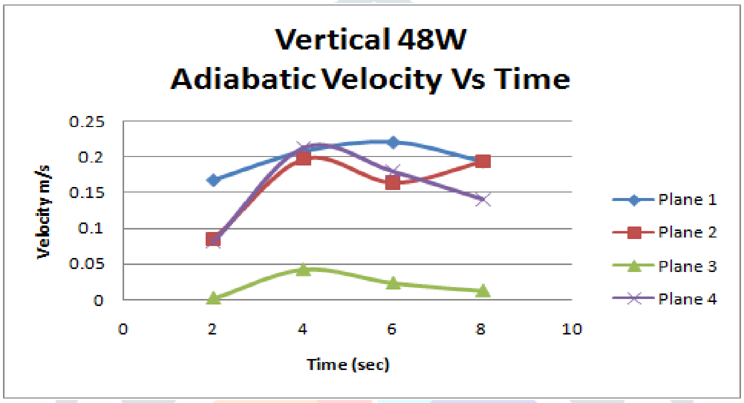

Fig. 6.7 Adiabatic: Variations in velocity of fluid in various planes over time at 48W

The main objective to include adiabatic section is to give the working fluid a lot where it can effectively dissipate the heat and to carry taking place in the evaporation and condensation mechanism and maintaining the pulsating flow, rather than losing heat to the surroundings, where there is no means to abandon the heat from the equipment, where PHP is installed, damaging it further. Hence, increase or decrease in velocity occurring in this section is purely the pulsating action of the condensed fluid and the vapour bubbles, indicating no phase changes.

Evaporator Section*:*

Velocity variation has also been plotted for evaporator section as shown in the Figs. 6.8 to 6.10, in order to examine the formation and movement of vapour bubble in evaporator section.

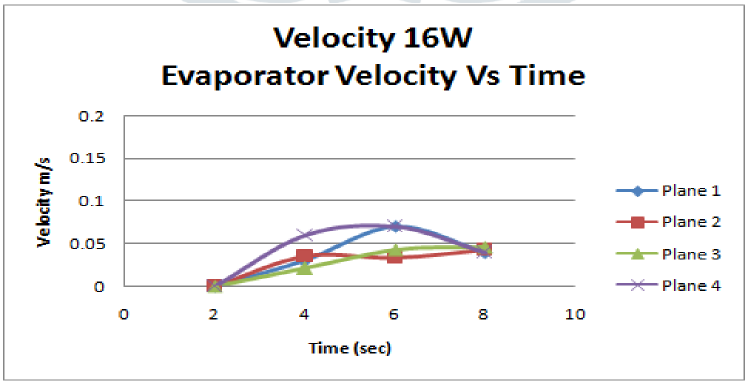

Fig. 6.8 Evaporator: Variations in velocity of fluid in various planes over time at 16W

In the evaporator section where the vapor bubble formation initiates, at 16W heat input, it is observed that the velocity rates throughout all the planes more or less the same as shown in the Fig. 6.8 This proves that evaporation phenomenon in the initial stages are evenly carried out in all the tubes (both the U- bends at the bottom) or in other words uniform circulation of heat can be inferred.

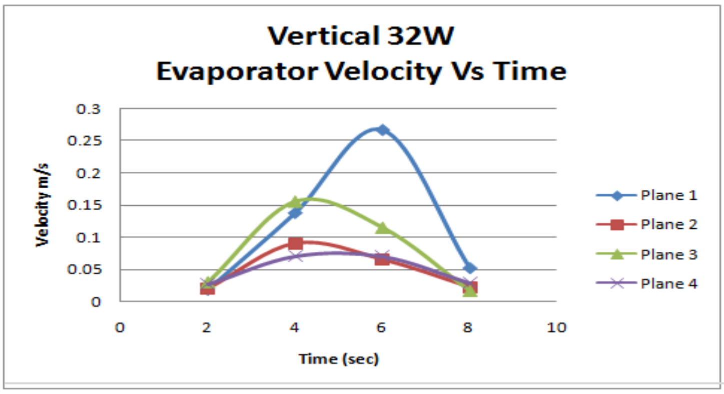

Fig. 6.9 Evaporator: Variations in velocity of fluid in various planes over time at 32W

At 32W an increase in the velocity is witness in Plane 1 and Plane 2as shown in the Fig. 6.9, which states the upward movement of the vapor bubble. However at 6sec the velocities are observed to decrease in the same planes caused by, not only the condensation phenomenon at the top but also the flow of vapour bubble through the two bends at the bottom of the evaporator.

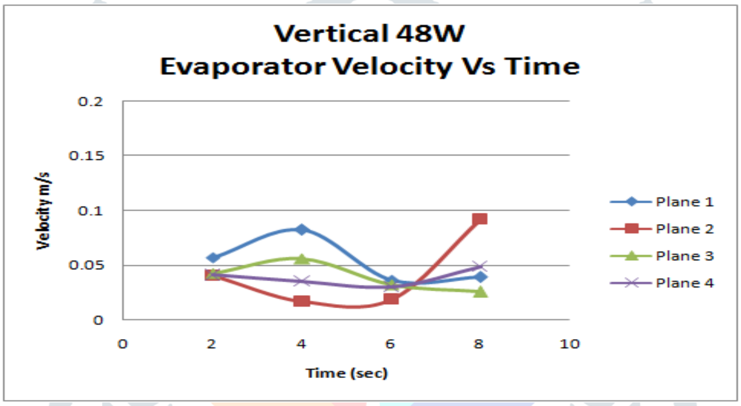

Fig. 6.10 Evaporator: Variations in velocity of fluid in various planes over time at 48W

At 48W evaporation phenomena is not the same in all legs of evaporator section, as a drop in the velocity is observed in Plane 1 and Plane 2 due to uneven distribution of heat in the pipes as shown in the Fig. 6.10. Further a decrease in the velocities is observed, which might be accounted as a reason for instabilities at higher heat input. Hence these velocity variations in various sections as shown in Figs. 6.5 to 6.13, gives an insight on the pulsating phenomena in terms of the velocities. The inference discussed states the formation of vapour bubble train, movement of the same from the evaporator to the condenser via adiabatic section and finally movement of the condensed fluid back to the evaporator, hence viewing a complete circulation phenomena of fluid. In each section of PHP, the velocity variations matched well with that of corresponding pressure variations

VII.CONCLUSIONS

In the present research performance analysis has been carried out onCLPHP using CFD analysis with various orientations, viz., vertical, inclined at 45^{o} and horizontal, by varying the heat input such as 16W,32W,48W.And also pulsating phenomenon has been studied. Thermal Resistance is obtained for each cases and those results compared with each other to find the best operating position. These are the conclusion obtained from based on results.

- CLPHP offered a well performance when operated in vertical position with low thermal resistance as compare to the other two positions within the operating conditions.
- The operating condition of CLPHP at horizontal position offered poor results.
- The inferences discussed clearly states the formation of vapour bubble train, movement of the same from the evaporator to the condenser via adiabatic section and also movement of the condensed fluid back to the evaporator.

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