CFD Simulation Analysis of Closed Loop Single Turn Pulsating Heat Pipes (PHP) by using ANSYS CFX Software

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Abstract* - Pulsating Heat Pipe (PHP) uses latent heat of vaporization & condensation to transfer heat between the evaporator region and the condenser region. Vapor plugs and Liquid slugs are formed in PHP due to the capillary action. The range of parameter for the tube has been decided on the basis of practical considerations of the system and operating conditions. CFD modeling is done in ANSYS CFX with single turns of PHP with length and diameter of the pipe as 86 mm and 3 mm respectively. A range of fluid fill ratio 40%, 60% & 80% for Methanol is considered. Similarly, for different power range 10 W to 70 W evaporator section is supplied with constant heat flux of 4423 (W/m^2 K), negative heat flux for condenser section & zero for adiabatic section. The CFD analysis is performed, and the outputs of the simulations are plotted in graphs and contours. It is concluded that, among three fill ratios, PHP with 60% fill is observed to be most suitable under different operating conditions. It is observed that the thermal resistance decreases, and heat transfer coefficient increases with increase in heat flux due to chaotic fluid movement. Decrease in the methanol temperature at the evaporator suggests that heat is carried away to the condenser part. Change in volume fractions of methanol and air in three regions viz. evaporator, adiabatic region and condenser reflects to the flow pattern of the fluid inside the PHP.

Keywords: Pulsating Heat Pipes (PHP), Methanol; Two Phase Flow, Computational Fluid Dynamics (CFD), CFD Simulations, Methanol –Methanol Vapor, Heat Transfer, Different Fluid Fill Ratio,ANSYS CFX, Pulsating Heat Pipes New Geometries & Working Fluid etc.

1. INTRODUCTION

Pulsating heat pipes (PHP) are advancement in the field of heat pipe innovation. Initially created and patented by HisateruAkachi in 1990, PHPs comprise of a long wandering cylinder which is warmed and cooled at different focuses with the length. Their activity depends on the rule of swaying for the working liquid and a stage change wonders in a fine cylinder. The breadth of the cylinder must be little enough with the end goal that fluid and fume plugs exist. Not at all like customary heat pipes, OHPs needn't bother with a wicking structure to move the fluid and can work at higher warmth motions.

This presents a computational report on the heat transfer qualities of shut circle Pulsating heat pipes (PHP). Anyway, demonstrating of a CLPHP framework in GAMBIT has many testing issues because of the intricacy and multi-material science nature of the framework. In this way, the shut circle throbbing warmth pipe displayed here has no wick material inside it as it presents in heat pipe. The shut circle throbbing heat pipe has no unpredictable structure so it is to be displayed. Stream representation was directed for the shut circle throbbing heat pipe utilizing ANSYS Fluent 14.5. With fitting limit conditions, we can picture the conduct of the model and make forecasts with respect to its presentation. Water-water fume and ethyl liquor - ethyl liquor fume is taken as the working liquid and heat transition is provided at the bay. Wonders, for example, nucleation bubbling, development of slug and spread of idleness wave were seen in the shut circle PHPs. Likewise, the examination has been done to know the conduct of PHP under shifting flexibly of warmth motion at the gulf (evaporator).for this, the yield heat motion is acquiring at outlet (condenser) and discover how the warmth transition is fluctuating for various heat motion and the diverse working liquid. Watchwords: - two stage stream, convective warmth move, bubbling and buildup.

Li, Q., Wang, C., Wang, Y., Wang, Z., Li, H. and Lian, C., (2020) In this paper, a mathematical model of the Pulsating Heat Pipe (PHP) is set up, in view of the two-stage stream hypothesis and the Volume of Fluid (VOF) technique in Computational Fluid Dynamics (CFD). Under the condition that the structure, fluid Filling Rate (FR) and warming intensity of the PHP stay unaltered, the impact of the length and the convective warmth move coefficient of the adiabatic area on the beginning up execution, heat move execution and hostile to dry-out capacity of the PHP are concentrated by changing the adiabatic segment boundaries. The outcomes show that, with the expansion of the adiabatic segment length, the beginning upseason of the PHP becomes more limited, however the warm opposition increments and the counter dry-out capacity is debilitated. At the point when the adiabatic segments assimilate heat from an external perspective, with the expansion of the convective warmth move coefficient, the switch of the beginning up time is generally little, however the warm obstruction increments, and the counter dry-out capacity is debilitated. At the point when the adiabatic segments disseminate warmth to the outside, with the expansion of the convective warmth move coefficient, the switch of the beginning up time is moderately little, yet the warm obstruction diminishes, and the counter dry-out capacity is improved. Nearly, while considering the warmth trade between the adiabatic segments and the climate, lower surrounding temperature is more helpful for improving the counter dry-out capacity of the PHP.

E. R Babua,(2018) Pulsating heat pipe is a compelling technique for heat move through inactive two stage system. In the current exploration work, trial contemplates were performed on throbbing warmth pipe produced using copper tube having inside and outside distance across of 2 mm and 3 mm individually. The throbbing warmth pipe is accused of acetylene as working liquid with various filling proportions of half, 60%, 70%, 80%, and 90% of its volume. The evaporator zone is electrically warmed by methods for mica warmer with a scope of 10 to 60 Watt and condenser segment is cooled by methods for cooling water at a consistent stream rate. The impact of filling proportion on warm execution of shut circle throbbing warmth pipe was explored. The outcome shows that, the warm opposition diminishes quickly with the expansion in the warming info and it is seen that lower estimation of warm obstruction is gotten at a filling proportion of 60%. Thus,acetylene displays better execution at a filling proportion of 60%.

Sedighi E, Amarloo A, Shafii B.,(2018) In addition to some approaches, for example, changing the working liquid or number of turns in a level plate pulsating heat pipe (FP-PHP), mathematical changes are additionally engaging for upgrading the heat execution of this sort of heat pipes. The fundamental thought of this examination is to build heat move rate by expanding stream dissemination of working liquid. By setting extra branches in the evaporator area, auxiliary air pocket siphons were made which improved the flow of liquid inside the FP-PHP. To examine the effect of these extra branches, two comparative four-turn aluminum FP-PHPs were created. One of them was the regular FP-PHP and the other had four extra branches and is named extra branch FP-PHP (AB-FP-PHP). Warm exhibitions of these two kinds of warmth pipes were researched at various filling proportions (40, 50, 60, and 70%) and heat.

2. CFD SIMULATION

2.1 Methodology

Above all else the writing review is done on the activity and execution of pulsating heat pipe. Relevant recommendations made on the papers and journals are considered to come up with the defined problem statement. In such manner, the paper by J.Venkatasuresha and P.Bhramara et. al. [1] is taken as the reference paper for the essential geometry, working conditions and execution boundary. This paper is reviled a wide variety of investigation can be done on PHP in future. Later the tools for solving the model is decided and worked on. After setting suitable schemes, simulation is run till the desired convergence criteria are achieved. Result of the CFD analysis of pulsating heat pipe can be displayed using contours, streamlines, chart or graphs. These data from the result are categorized and then compared with our basic reference.

2.2 Geometry and Meshing

2.2.1 Geometry

Performance Evaluation of Pulsating Heat Pipe is being carried out using Computational Fluid Dynamics platform. For this the modeling of heat pipe with all the constituent components is done in Solid Works. Figure.1 displays the entire geometrical dimension involved with length and diameter of the pipe as 86 mm and 3 mm respectively. The pipe is made up of copper. Methanol and Methanol vapor is taken as the working inside the pipe with 3 mm internal diameter & 1 mm thickness.

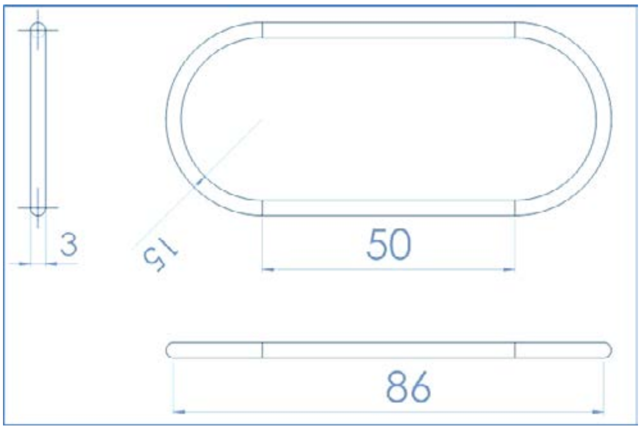
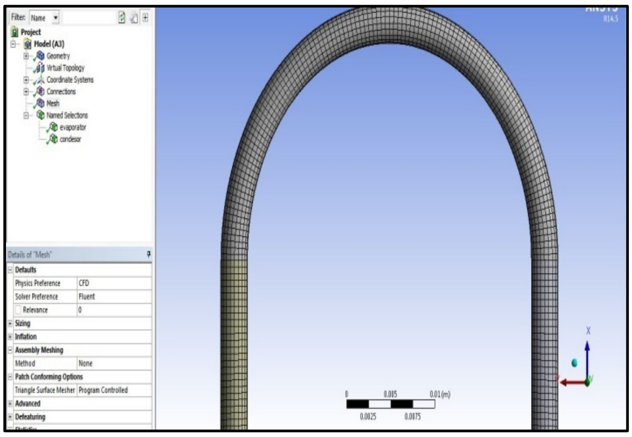


Figure1: Schematic diagram of Single loop Pulsating Heat Pipe (All dimensions in mm)



Defaults	
Physics Preference	CFD
Solver Preference	Fluent
☐ Relevance	0
Sizing	
Inflation	
Assembly Meshing	
Method	None
Patch Conforming Options	
Triangle Surface Mesher	Program Controlled
Advanced	
Defeaturing	

Figure 2: A Small Section of Geometry Meshed in Gambit

2.2.2 Meshing

Notwithstanding the robotized settings, ANSYS Meshing furnishes extra control with the alternative to indicate blends of point controls, edge controls, surface controls and additionally body controls. Every last one of these has its own choices and can be utilized to impact the cross section in an unexpected way. In this case, the automatic method for mesh shape is selected; however, the sizing for the mesh is done manually. is the meshing section where the sections of the geometry are given name which makes easy while defining domain and giving boundary conditions?

2.3 Analysis Setting

Steady state examination is done on CFX in the primary stage. In spite of the fact that the vast majority of the thermal examination is done with transient case, steady state investigation is run just to be certain that this case is of steady state examination or the transient. The distinction between a steady state and transient analysis is that steady state overlooks a significant number of the cross terms and higher derivatives dealing time. These terms all go to zero in steady state so they don't influence the steady state result. On the other hand transient analysis incorporates each one of these terms. Normally this implies the steady state model has a simpler convergence as there are less terms to display and some transient non-linearity are taken out, yet in a couple of models these non-linearity help convergence (yet this is rare).

For the transient state investigation diverse methodology of simulations, viz. time steps, time steps for run and versatile techniques were done as a trail. Later the time steps alternative is decided to continue with. Given the quantity of cross sections and the stream speed of the liquid in the space, bigger time steps couldn't be utilized. This limits the reproduction to be finished with more modest time step size. No outside solver coupling was done as there is no need of that, since all the boundaries, going from math, lattice to the space settings was performed under a similar document; and the picked solver for example CFX is able in addressing the very case all alone.

2.4 Basic settings for domains

Primarily three domains were characterized for the general geometry of PHP, viz. condenser, adiabatic section and evaporator. Also, the adiabatic area is separated into two areas to consolidate the methanol-methanol vapor level ascent in the PHP from the evaporator at the base.

2.5 Boundary Condition

Four Different heat fluxes i.e., 10W, 30W, 50W and 70W were given to Evaporator section. Zero Heat flux is for Adiabatic Region & negative heat flux was given in condenser section. Volume of fluid (VOF) model is used for the CFD analysis. In all domains, the walls are of no slip wall types. All the walls are assumed smooth with no slip condition.

2.6 Turbulence Model

Keeping in mind of an industry standard model, the k-epsilon model has been selected as the most promising turbulence model for analysis of CFD codes. It has demonstrated to be stable and mathematically vigorous and has a grounded system of prescient ability. For universally useful reproductions, the k-epsilon offers a decent trade off as far as precision and vigor.

2.7 Condenser

In condenser region, all components of velocity (u, v and w) are provided as 0 m/s and relative pressure, 0 kPa. As per the problem statement the volume fraction value for air is 1, and binary mixture fluid and vapor both are set to 0 volume fraction. After the heating of evaporator is heated, if the binary mixtures thermal boundary condition with fixed temperature of 302 K is set.

2.8 Evaporator

In evaporator also all the components of velocity is set to 0 m/s and relative pressure to 0 KPa. As far as volume fractions are concerned values of 1, 0 and 0 is provided for Methanol, methanol vapor and air respectively .In adiabaticregions the boundary condition is adiabatic which defines the heat flux rate as 0 W/m2K. Likewise in evaporatorregion, where the external heat source is attached, total constant heat flux of value 4423 W/ m2 K.

3. RESULTS AND DISCUSSIONS

The result of the CFD analysis of pulsating heat pipe can be calculated in many ways like the analysis on the basis of contours, streamlines, chart or graphs.

Table1: Tables showing the temperature variation of Condenser & Evaporator against various heats input & fill ratio

HEAT INPUT In Watts	**EVAPORATOR**			**CONDENSOR**		
	Temperature (K)			**Temperature (K)**		
	FR (40%)	(60%)	(80%)	FR (40%)	(60%)	(80%)
10	321	321	322	300	300	300
30	329	322	325	300	300	300
50	339	334	335	300	300	300
70	343	343	341	300	300	300

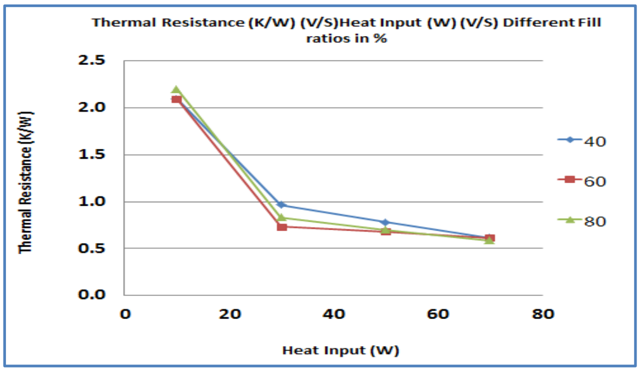


Figure 3(a): Graph of Thermal Resistance (K / W) Vs Heat Input (For different fill Ratio)

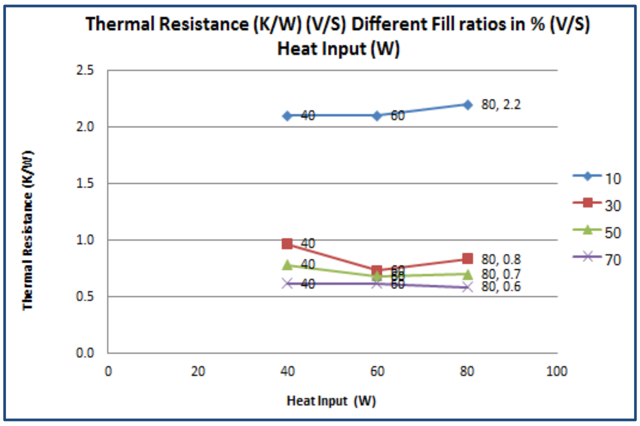


Figure 3 (b): Graph of Thermal Resistance (K / W) Vs Different Fill Ratio (For different Heat Input)

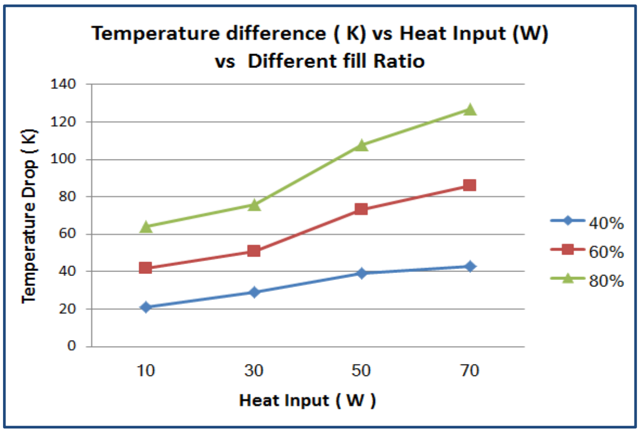
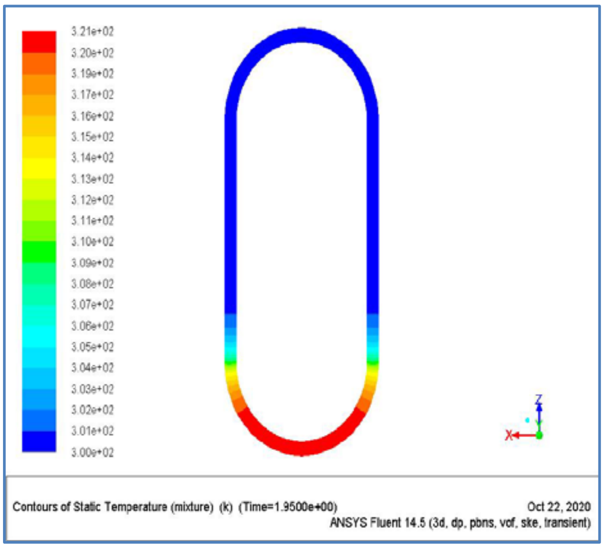


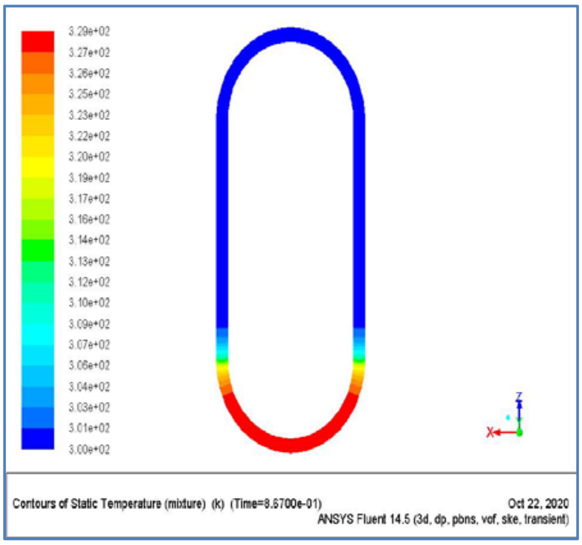
Figure 3(c): Graph of Temperature Drop (K) Vs Heat Input (W) (For different fill Ratio)

The various parameters for the different time steps are noted (as shown in table 1) and that value are used for plotting the graph. The temperature of working fluid i.e., Methanol at evaporator and condenser are plotted, and also volume fractions of methanol and methanol vapor at condenser and evaporator are plotted so as to get the clearer picture of the output.

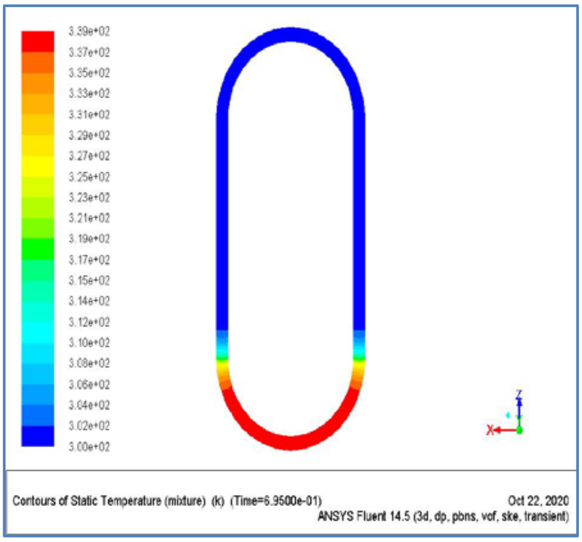
3.1 Static Temperature Contour for 40 % fill Ratio against different Heat Input



Heat Input 10w (v/s) Fill Ratio 40%



Heat Input 30w (v/s) Fill Ratio 40%



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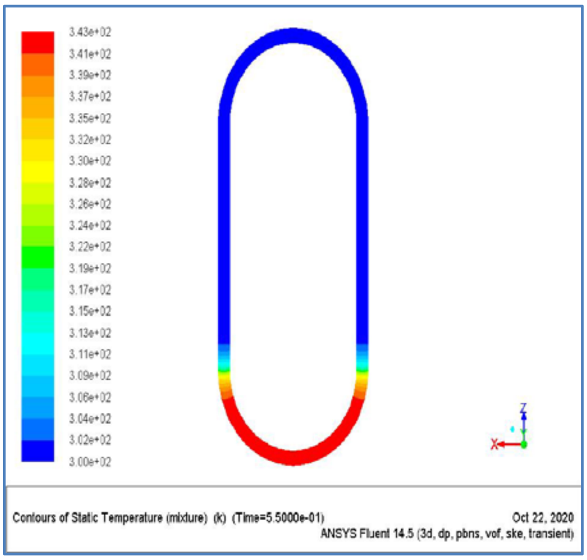
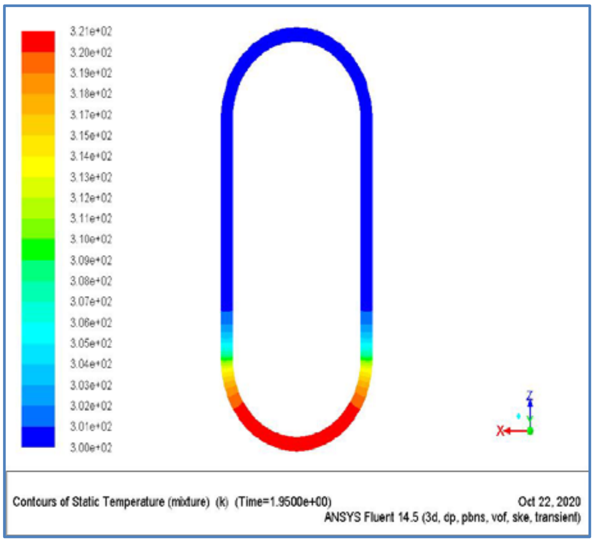
Heat Input 50w (v/s) Fill Ratio 40%

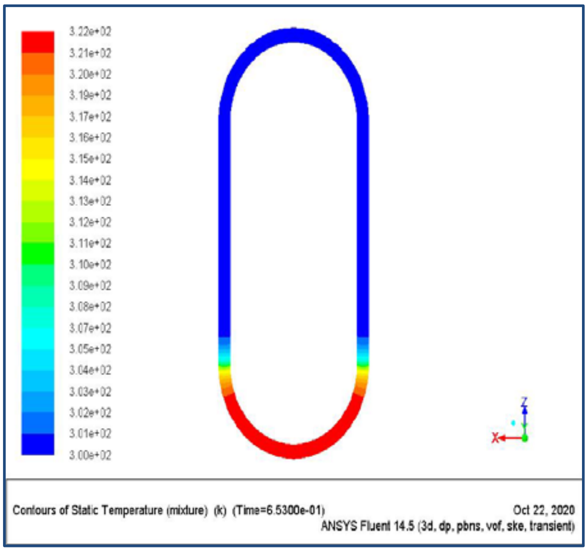


Heat Input 30w (v/s) Fill Ratio 40%

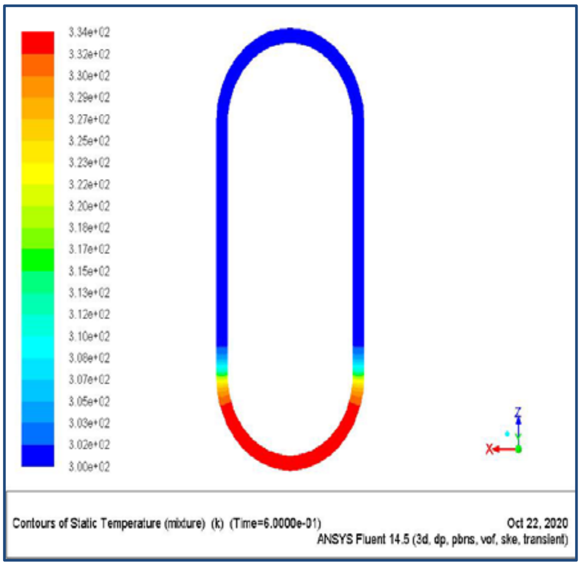
3.2 Static Temperature Contour for 60 % fill Ratio against different Heat Input



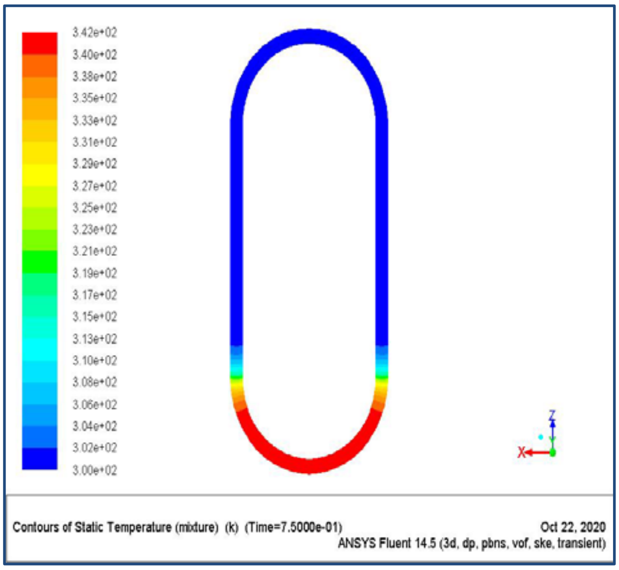
Heat Input 10w (v/s) Fill Ratio 60%



Heat Input 30w (v/s) Fill Ratio 60%

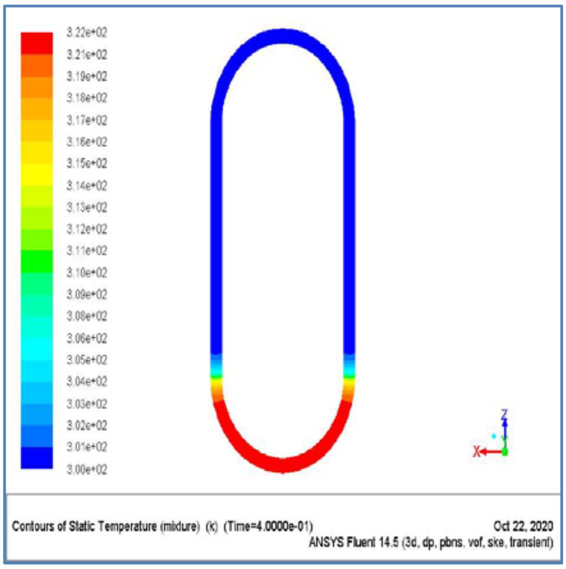


Heat Input 50w (v/s) Fill Ratio 60%

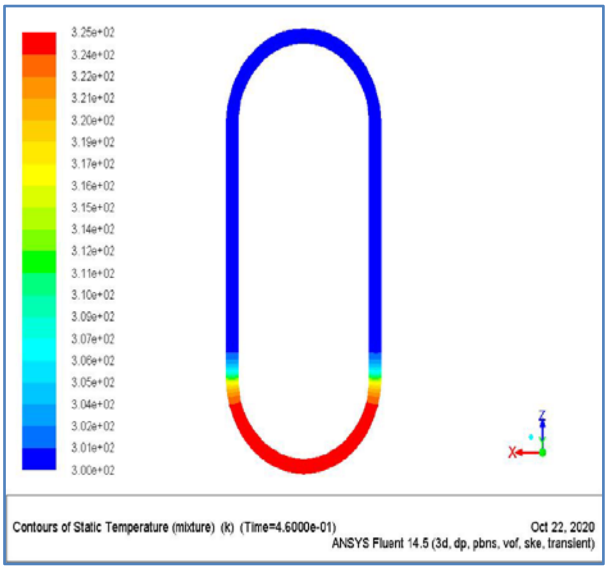


Heat Input 70w (v/s) Fill Ratio 60%

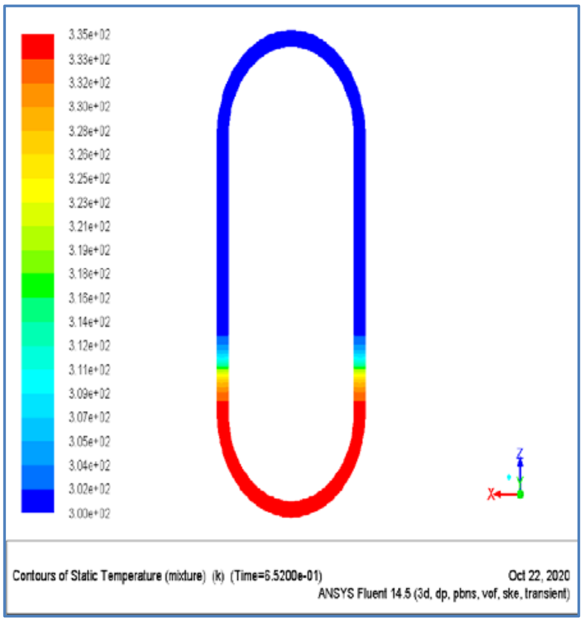
3.3 Static Temperature Contour for 80 % fill Ratio against different Heat Input



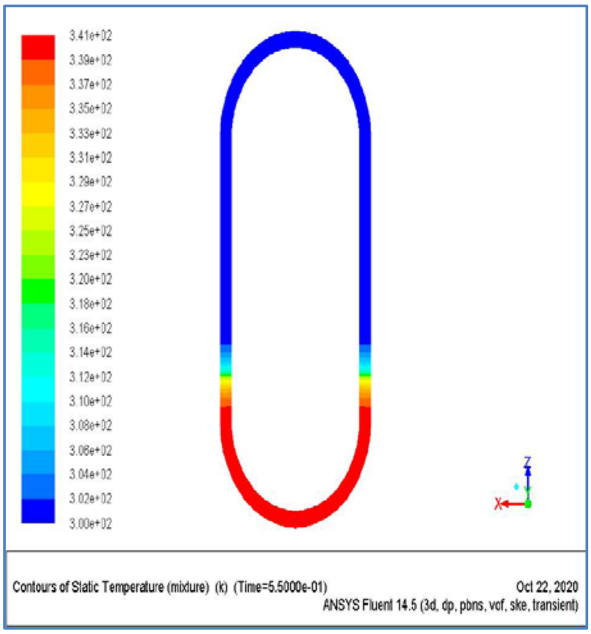
Heat Input 10w (v/s) Fill Ratio 80%



Heat Input 30w (v/s) Fill Ratio 80%



Heat Input 50w (v/s) Fill Ratio 80%



Heat Input 70w (v/s) Fill Ratio 80%

4. CONCLUSION

- It can be concluded that two phase flow is successfully simulated in CFX for closed loop pulsating heat pipe.
- With methanol as working fluid & with different fill ratio (i.e., 40%, 60% & 80%), 60 % is observed to be more suitable under different operating conditions.
- It is observed that the lowest value of thermal resistance is obtained with 60% fill ratio for various heat inputs (i.e., 10W, 30W, 50W & 70W) respectively.
- The thermal resistance of closed loop pulsating heat pipe decreases with the increase of heat input.

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