COMPARATIVE ANALYSIS OF A CLOSED LOOP PULSATING HEAT PIPES (CLPHPs) ON THE BASIS OF THEIR MATERIAL AND WORKING FLUID

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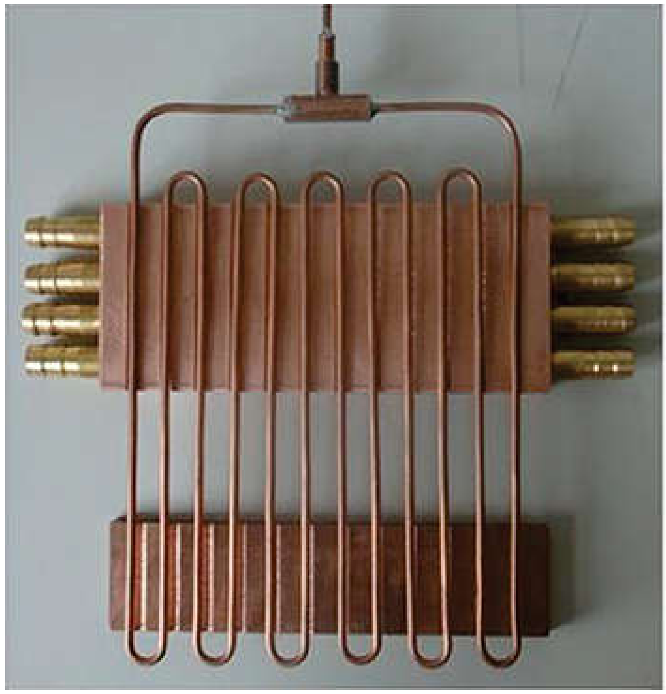
ABSTRACT
This paper presents the analysis of various heat pipes and draws a comparison among them.The comparison of the effectiveness of a heat pipe is done by plotting condenser temperature as a function of time. The higher the temperature reached condenser end, higher is the efficacy of the heat pipe. A high-temperature difference is kept between condenser and evaporator section (100-degree celsius) to reduce computation time and to get substantial results. VOF model is used to simulate the working of the heat pipe.

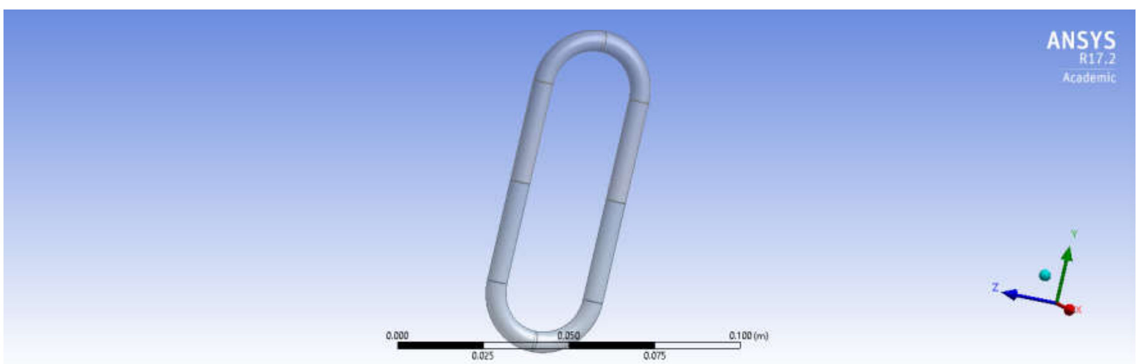
KEYWORDS:- closed loop pulsating heat pipe, condenser, evaporator, time stop, wall heat transfer coefficient, VOFmodel

1. INTRODUCTION

Heat pipe was developed in the early 1960s, and since then this technology has evolved into many different shapes and forms. A heat pipe is a heat transfer device that uses both the principles of Thermal conductivity and Phase transition in a combined way to efficaciously transfer heat between two solid interfaces[1].Heat transmission takes place at higher rates over significant distances with the extremely small temperature drop, remarkable flexibility .It's construction is simple and easy to control with no external pumping[2].In a closed loop pulsating heat pipe (CLPHP)the, slug/plug motion of the working fluid in the tube is the driving force which is generated due to evaporation. PHP consists of a tube bent to form several parallel channels. It can be categorized into two types as an open and closed loop.In the open loop, one end of the PHP is strained-off, and then welding is done; in contrast, the other end presents a service valve for vacuum and charge (this valve can be removed later)[3]. While in the latter one, the heat pipe is in the form of a closed loop. The mechanism through which fluid is circulated in the heat pipe is the capillary action. This is possible due to vacuum inside the heat pipe. The absolute pressure inside the CLPHP is around 4000-5000 Pascal. Invented in the 1990s, pulsating heat pipe (PHP) that has potential applications in solar cell, fuel cell, space and electronic cooling (such as in the cooling of graphics cards in laptops). The CFD analysis of this heat pipe is done using ANSYS software(version 17.2). For this analysis, Aluminium, Copper, and Steel have been chosen as the heat pipe material keeping the water as the working fluid. While in the second part of the analysis, Aluminium is chosen as the heat pipe material using different working fluids(Water, Ethanol, and Ammonia). The purpose of this analysis is to determine the effectiveness of various heat pipes under identical operating conditions and to signify the importance of heat pipes as heat exchangers.



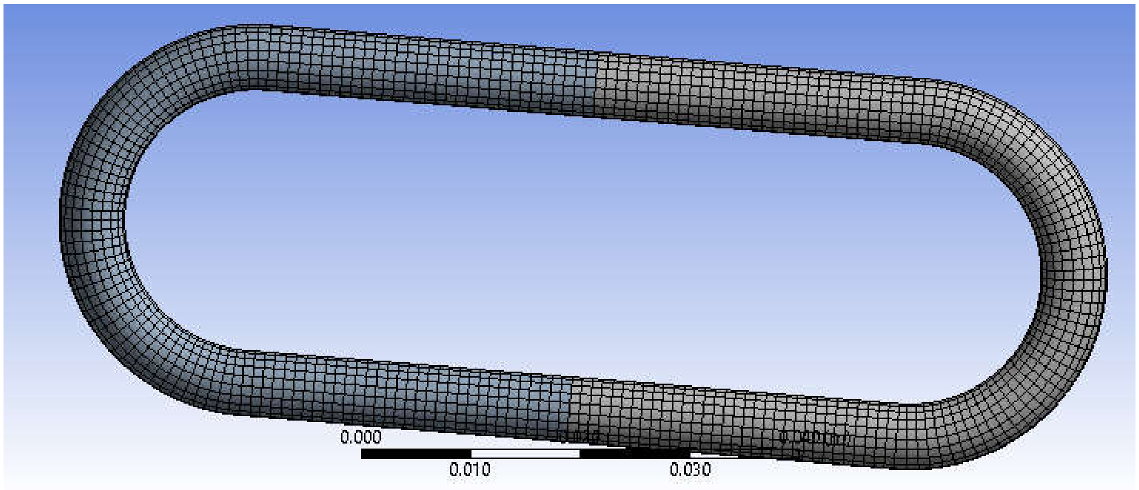
2. GEOMETRY OF CLPHP



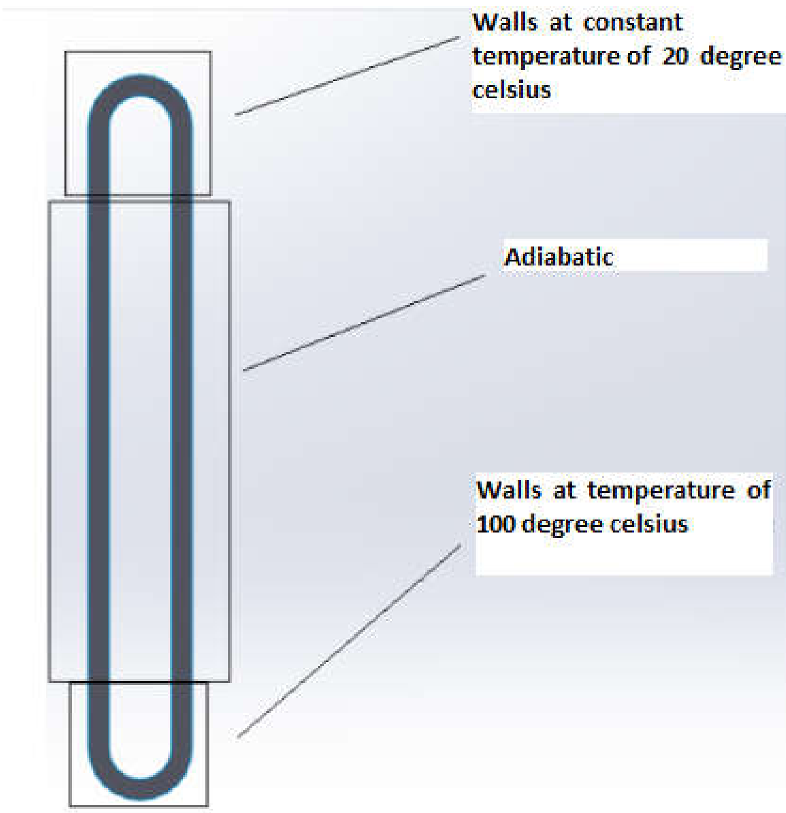
The geometry is created using CATIA V5. First, a rectangle of dimensions 30mm x 90mm is created, and then fillet is applied to each of the corners of the rectangle of radius 15mm. After this, a semi-circular profile of radius 3mm is swept along this rectangle. Thus, giving the entire geometry a semi-circular cross-section.It is imported to ANSYS using .igs extension.

3. MESHING

Meshing is also done with the help of ANSYS software. Fine meshing scheme is used, and the analysis consists of 23655 nodes and 4407 elements. Curvature size function is used for meshing purpose. Below is the schematic of the meshing.



4. SETUP:



As shown in the above figure, the bottom portion(heat source or the heater section) is maintained at a temperature of 393K while the upper section (heat sink or condenser) is initially kept at a temperature of 293K. The middle portion of the heat pipe is adiabatic and ensures proper heat conduction within the heat pipe. The analysis of this heat pipe is done using ANSYS Fluent. VOF(Volume Of Fluid) method is adopted for the solution. The analysis consists of three Eulerian phases namely the working fluid in liquid phase, the working fluid in the vapor phase and air. The primary phase is air, the secondary phase is the working fluid in the liquid form, and the tertiary phase is the working fluid in the vapor form. Transient scheme of analysis is adopted. Gravity is the only body force. It has been assigned in the proper direction. Along with this, energy equation is also used. The standard k-epsilon model is used along with enhanced wall treatment, curvature correction, and implicit body force. A constant pressure of 4000 Pascal is maintained inside the heat pipe, and operating temperature is 288.15K. Initially, the working fluid in the liquid form is patched in half of the heat pipe while air is patched in the other half. Due to the vacuum maintained inside the heat pipe, evaporation of water(if used as working fluid) takes place at 308K(instead of 393K at 1 atm). Surface tension modeling along with wall and jump adhesion is also implemented.

5. Time-step

The biggest issue with the simulation of multi-phase flows is that the time step needs to be sufficiently small to capture the movement of the particles, at the same time it needs to be big to reduce the computation time. The most suitable time step for this simulation is 0.0005 seconds. To incorporate for long computation time, the analysis is done for 1 second using a large temperature difference of 100 degree Celsius. The computation time for each analysis is about 30 minutes.

Time step (s)	Issue
0.1	Diverges very fast
0.01	Diverges
0.001	Diverges after some time
0.0005	Takes a long time but doesn't diverge

6. Thermodynamic Relations Used

Navier-Stokes equation:

$$\frac{\partial u_v}{\partial x}+\frac{\partial v_v}{\partial r}+\frac{v_v}{r}=0$$

$$\rho_v\left(u_v\frac{\partial u_v}{\partial x}+v_v\frac{\partial u_v}{\partial r}\right)=-\frac{\partial P_v}{\partial x}+\mu_v\left(\frac{4}{3}\frac{\partial^2 u_v}{\partial x^2}+\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial u_v}{\partial r}\right)+\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial v_v}{\partial r}\right)-\frac{2}{3}\frac{\partial}{\partial x}\left(\frac{1}{r}\frac{\partial}{\partial r}(rv_v)\right)\right)$$

$$\rho_v\left(u_v\frac{\partial v_v}{\partial x}+v_v\frac{\partial v_v}{\partial r}\right)=-\frac{\partial P_v}{\partial r}+\mu_v\left(\frac{\partial^2 v_v}{\partial x^2}+\frac{4}{3r}\frac{\partial}{\partial r}\left(r\frac{\partial v_v}{\partial r}\right)-\frac{4}{3}\frac{v_v}{r^2}+\frac{1}{3}\frac{\partial^2 u_v}{\partial x\partial r}\right)$$

$$\rho_v c_{p,v}\left(u_v\frac{\partial T_v}{\partial x}+v_v\frac{\partial T_v}{\partial r}\right)=\frac{k_v}{r}\left(\frac{\partial}{\partial r}\left(r\frac{\partial T_v}{\partial r}\right)+r\frac{\partial^2 T_v}{\partial x^2}\right)+\mathrm{v}\frac{\partial p_v}{\partial r}+u_v\frac{\partial p_v}{\partial x}$$

Effectiveness of a heat pipe can be represented by a system of thermal resistance.The thermal resistance "R" can be represented by:

$$R=\frac{T_e-T_c}{Q}\ {}^\circ C/W$$

The overall heat transfer coefficient**, h** of the heat pipe can be given by:

$$h=\frac{Q}{A(T_e-T_c)}\ W/m^2\,{}^\circ C$$

Here, T_c = Average condensation Temperature

T_e = Average Evaporation Temperature

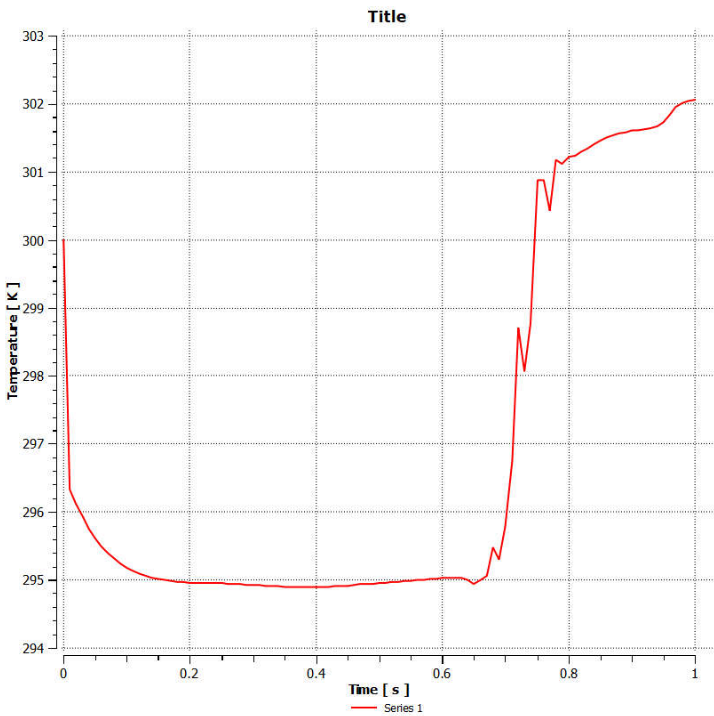
Q =Heat Input in watt

A = Heat Transfer Area At the Evaporator (in m^2)

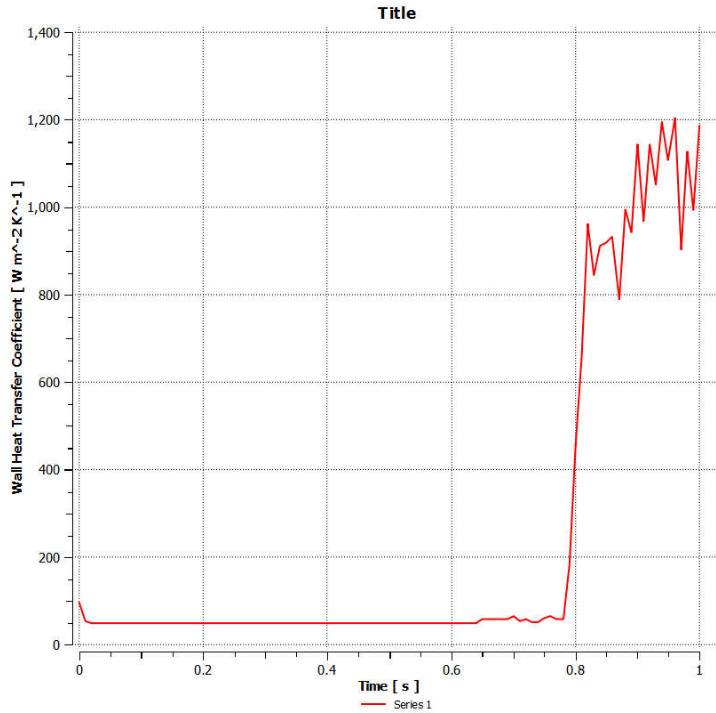
7. Analysis

- **ALUMINIUM HEAT PIPE USING WATER AS WORKING FLUID:**

a) **Condenser Temperature vs Time**

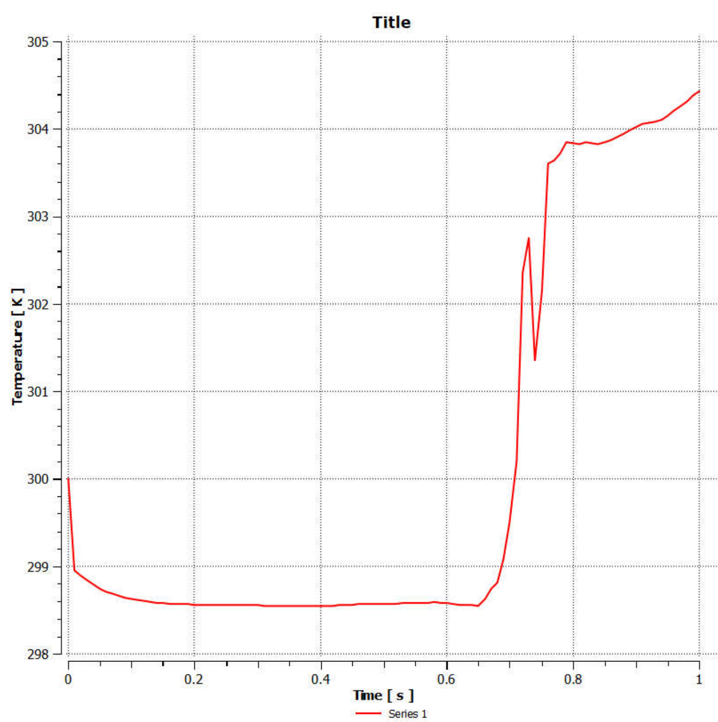


b) Condenser Wall Heat Transfer vs Time

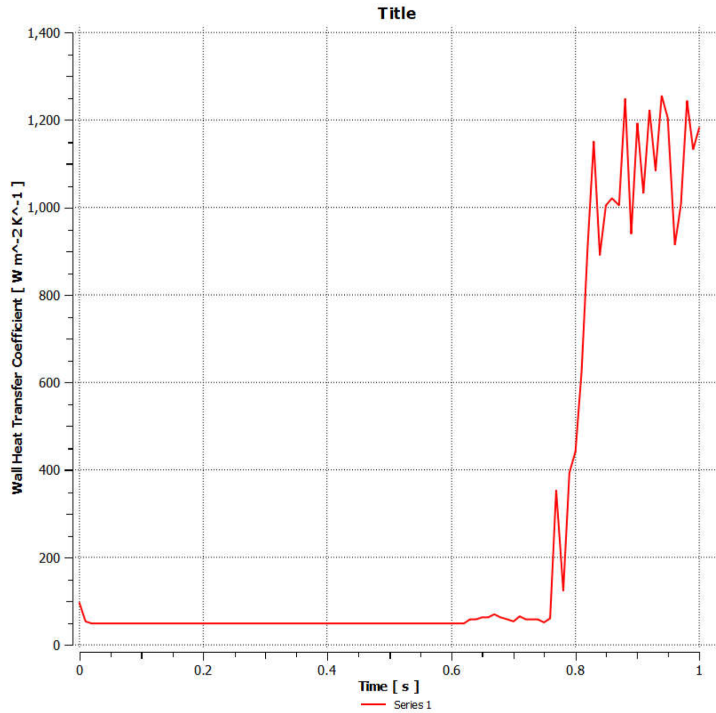


- **COPPER HEAT PIPE USING WATER AS WORKING FLUID:**

c) Condenser Temperature vs Time

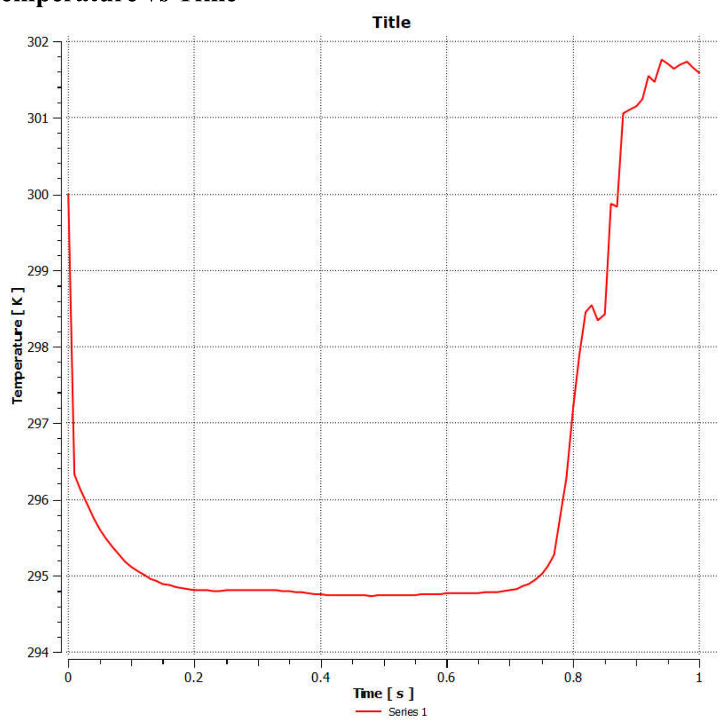


d)Condenser Wall Heat Transfer Coefficient vs Time

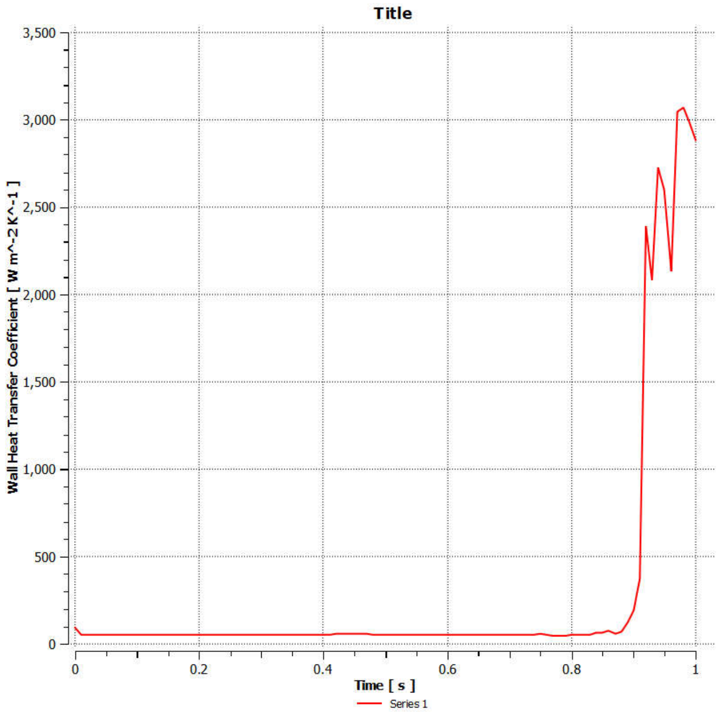


- **STEEL HEAT PIPE USING WATER AS WORKING FLUID:**

e) Condenser Temperature vs Time

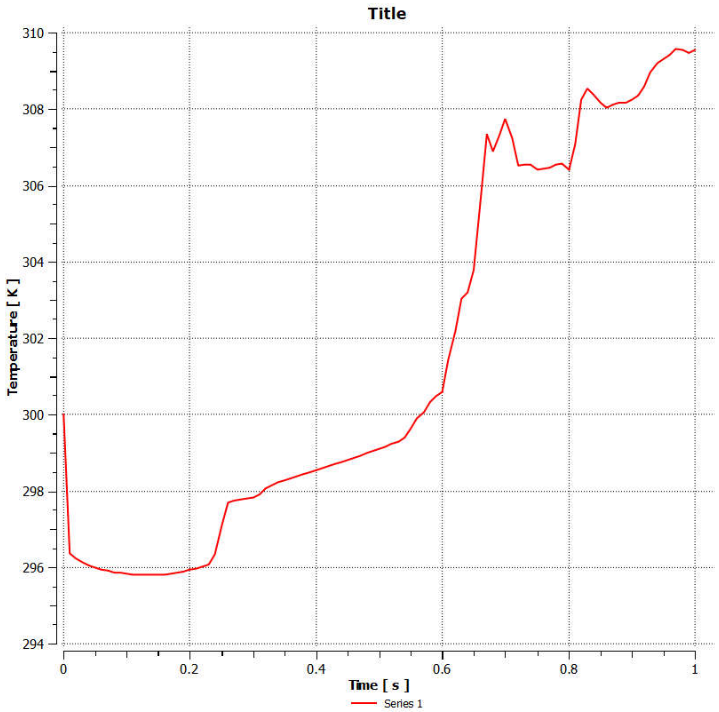


f) Wall Heat Transfer Coefficient vs Time

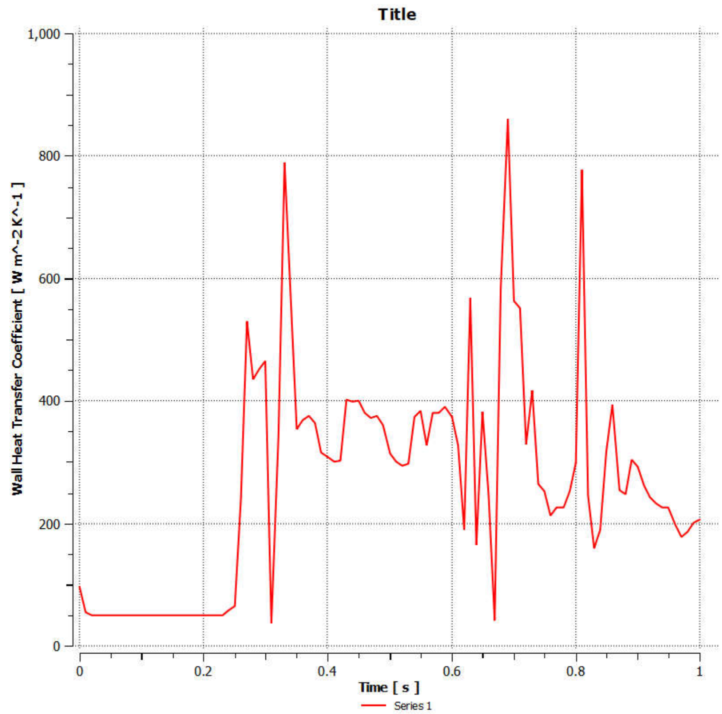


- **ALUMINIUM HEAT PIPE USING ETHANOL AS WORKING FLUID:**

g)Condenser Temperature vs Time

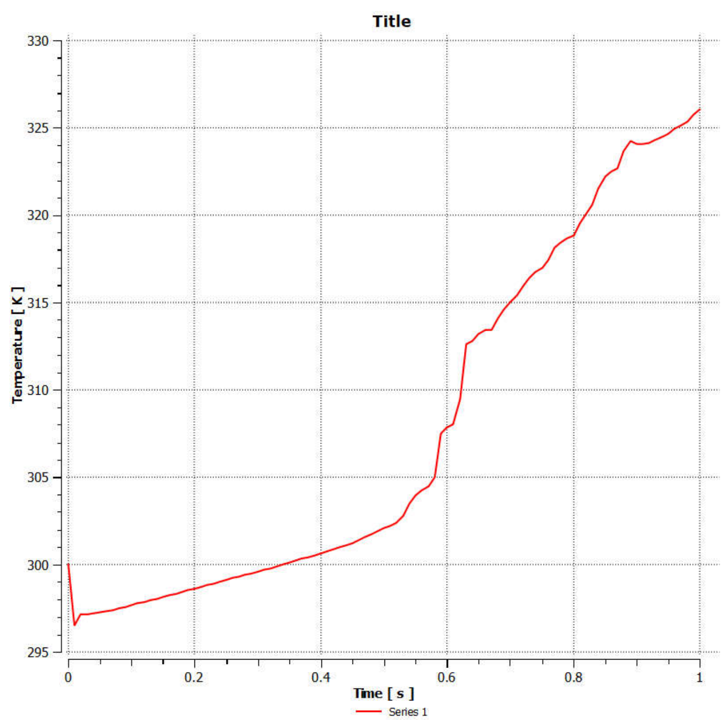


h) Wall Heat Transfer Coefficient vs Time

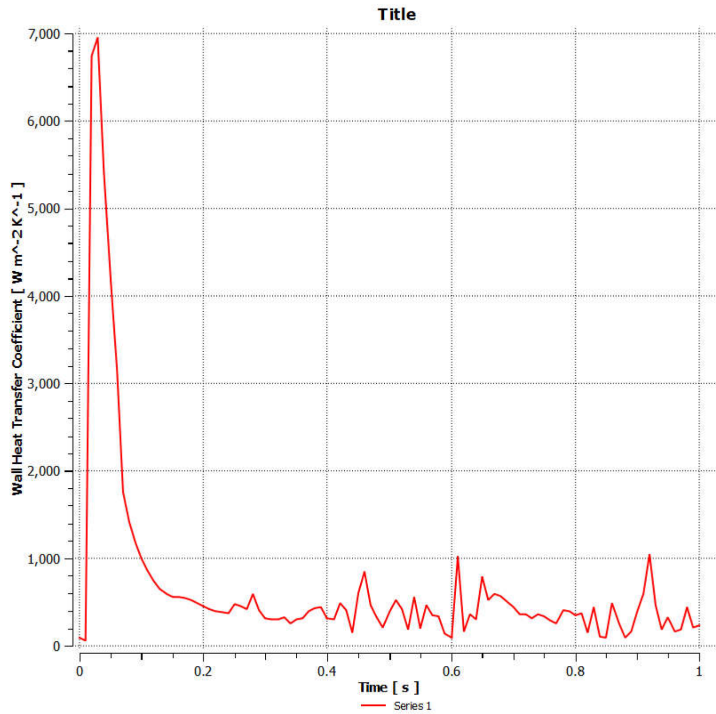


- **ALUMINIUM HEAT PIPE USING AMMONIA AS WORKING FLUID:**

  i) Condenser Temperature vs Time



j) Wall Heat Transfer Coefficient vs Time



8. Conclusion:

From various Condenser Temperature vs Time and Wall Heat Transfer Coefficient vs Time graphs obtained using ANSYS software, it can be seen that the performance i.e. the effectiveness with which the heat pipe carries away heat from evaporator to condenser section varies by changing the material of the pipe. The best performance is obtained by using aluminium heat pipe along with ammonia as working fluid. The temperature of condenser section rises appreciably with time in this heat pipe. Among copper, aluminium and steel, it is evident from the graphs that copper heat pipe yields the best result when working fluid is kept constant. Similarly, among water, ethanol and ammonia, the best performance is obtained using ammonia as working fluid when material of heat pipe is kept constant.

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